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TECHNICAL NOTE

# **PROGRAM BTLS TECHNICAL DESCRIPTION, SELECTION OF INPUT DATA, AND RUNNING INSTRUCTIONS**

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1982

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This Technical Note has been prepared to document the Bottom Loss Program that uses geoacoustic parameters to calculate Bottom Loss. It is intended to be a technical description of the Bottom Loss Program, a selection guide for input data, and a users instruction manual.

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This report documents the computer program BTLS which is used to compute geo-physical parameters of the ocean bottom from measurements of bottom loss of underwater sound and simulated bottom loss of underwater sound from geophysical parameters of the ocean bottom. Physical assumptions and the mathematical model used for the computations are discussed, and sources or derivations of all necessary equations used in the program are given. Guidelines are provided for interpretation of experimentally measured results and selection of input data to use in computations. Instructions are given for the input of data and		



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## PROGRAM BTLS DESCRIPTION

### I. INTRODUCTION

This is a description of the computer program entitled PROGRAM BTLS provided by Science Applications, Inc. (SAI) of McLean, Va. It is based mainly upon the principles discussed in an article by C.W. Spofford, R.R. Greene, and J.B. Hersey of SAI, "The Estimation of Geo-Acoustic Ocean Sediment Parameters from Measured Bottom-Loss Data," to be published in the Journal of the Acoustical Society of America, under contract to Naval Ocean Research and Development Activity, contract number NORDA SEAS N00 14-78-C-0211.

Individual statements, computations, or formulas used in the computer program and subroutines are discussed and analyzed in order to relate them more clearly to the physics and assumptions made by Spofford et al. (1982). This is done to enable the user to more readily have access to an understanding of the program and its proper utilization. It may also enable such modifications (if any) as may be desirable to be made.

The geo-acoustical model upon which Program BTLS is based is shown in Figure 1 which is reproduced below. The sediment is characterized by a compressional-wave sound-speed profile given by (equation 13 of Spofford et al. (1982)).

$$C(Z) = C_0 \left[ (1+B) \left( 1 + \frac{2 g_0 Z}{C_0 (1+B)} \right)^{1/2} - B \right] \quad (1)$$

where  $g_0$  is the gradient at the top of sediment,  $Z$  is the depth below the top of the sediment,  $C$  is the sound speed (with  $C(0)=C_0$ ), and  $B$  is a parameter which controls the shape of the profile. From this equation an expression for the sound speed gradient as a function of sound speed  $C(Z)$  is found to be (equation 14 of Spofford et al. (1982))

$$g(z) = \frac{dC}{dz} = g_0 \frac{(1+B)}{\frac{C(z)}{C_0} + B} \quad (2)$$



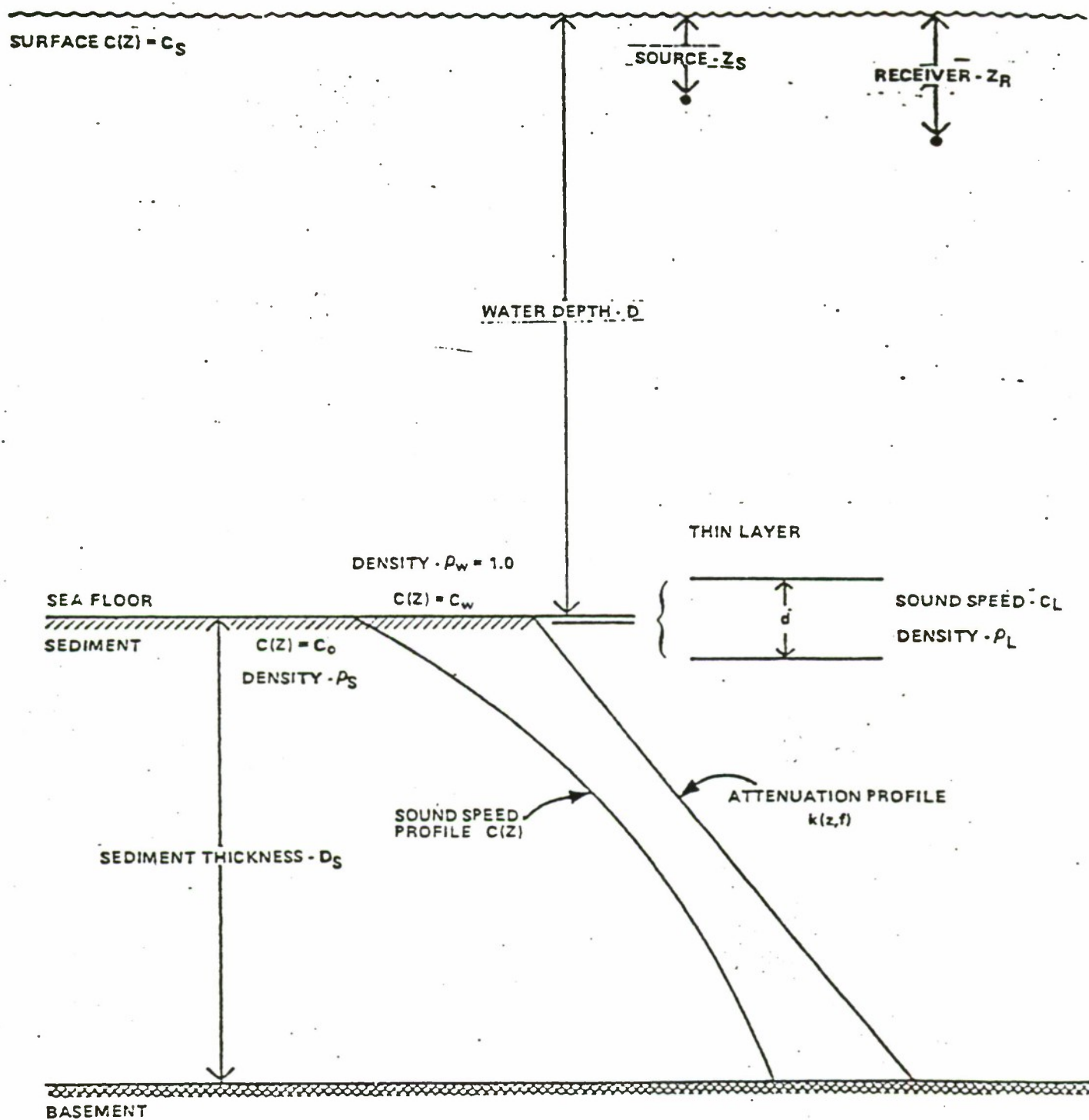


Figure 1. Simplified geo-acoustic model used to simulate bottom-loss measurements.

From Spofford et al. (1982)

These two equations are used for ray calculations involving the sediment and are of major importance in the model.

It is assumed in the model that a thin layer characterized by a high sound speed overlies the sediment, and at the bottom of the sediment there is a basement with acoustic properties different from the sediment.

Various possible ray paths for which computations are done by Program BTLS are shown in Figure 2.

Pages showing the GEO-PARAMETER INPUTS and INVERSION PARAMETER INPUTS follow Figure 2.

A copy of PROGRAM BTLS is provided for convenience in Appendix A, a computer derived flow chart is in Appendix B, and Appendix C contains a computer run stream example. The computer program and subroutines are discussed in the order in which they appear in the printout.



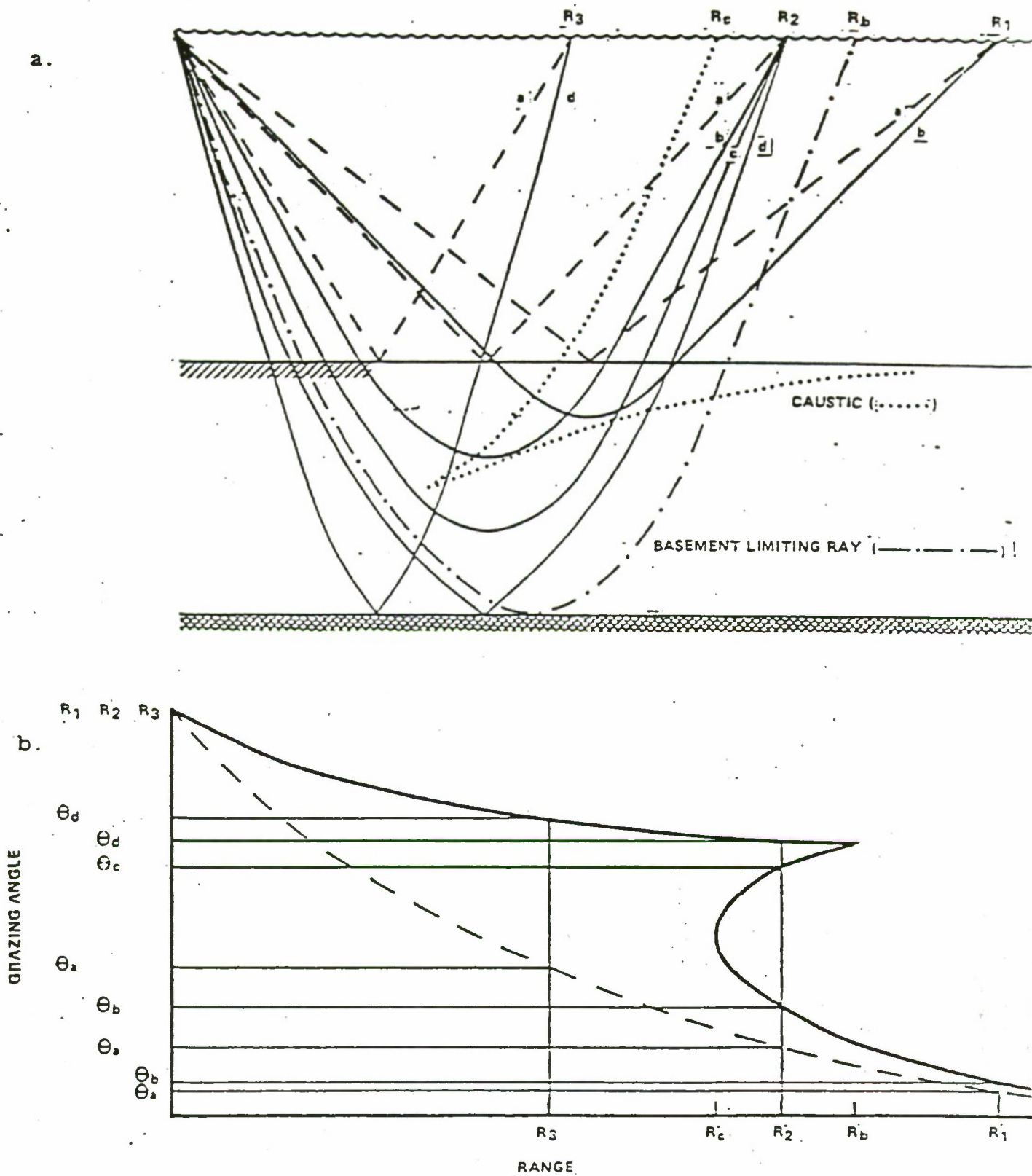


Figure 2. Ray paths (a) and angle-versus-range curves (b) for sediment reflected (—) and refracted/basement-reflected (---) paths.

From Spofford et. al. (1982)

TABLE 1. GEOPARAMETER INPUTS

INPUT CODE	PARAMETERS	UNIT
T	Two-way travel time thickness of sediment in tenths of second	0.1s
NNFILE	Arbitrary file or station number	
IOPT	Input Option: 0 for geo-parameters 1 for inversion parameters	
ZB	Water Depth	m
ZS	Source Depth	m
ZR	Receiver Depth	m
CS	Sound speed at source or receiver, whichever is shallower	m/s
C1	Sound speed at bottom of water	m/s
	GEO-ACOUSTIC PARAMETERS follow:	
RATIO	Ratio of speed in sediment to speed at bottom of water	-
G	Gradient at top of sediment	1/s
BETA	Cononical curve type	-
GAM	Attenuation profile gradient	dB/m <sup>2</sup> /kHz
REF	Basement reflection coefficient	-
ALPHØ	Surface sediment attenuation	dB/m/kHz
RH2	Thin layer density	g/cm <sup>3</sup>
RH3	Sediment density	g/cm <sup>3</sup>
D	Thin layer thickness in meters	m



TABLE 2. INVERSION PARAMETER INPUTS

INPUT CODE	PARAMETER	UNIT
T	Two-way travel time thickness of sediment in tenths of second	0.1 s
NNFILE	Arbitrary file or station number	
IOPT	Input Option: 0 for geo-parameters 1 for inversion parameters	
ZB	Water depth	m
ZS	Source depth	m
ZR	Receiver depth	m
CS	Sound speed at source or receiver, whichever is shallower	m/s
C1	Sound speed at bottom of water	m/s
DBLOSS FREQ	A value of loss, frequency and angle - example: DBLOS=7 frequency = 200 Hz angle = 20°	dB Hertz degrees
ALOSSØ	Low frequency loss level at high angles	dB
ALOSSM	Minimum loss level at high angles	dB
FM	Frequency of minimum loss (of ALOSSM)	Hertz (Hz)
TIR	Angle of total internal reflection	degrees
THC	Angle of caustic	degrees
RATIO	Ratio of speed in sediment to speed at bottom of water	-
G	Gradient at top of sediment	1/s
BETA	Canonical curve type Sound speed profile parameter	-
GAM	Attenuation profile gradient	dB/m <sup>2</sup> kHz
REF	Basement Reflection coefficient in pressure units	-

## II. THE PROGRAM

We now consider PROGRAM BTLS. If IOPT = 1, inversion parameters are computed as follows:

### OPTIONS AND ERROR CHECKING

The angle of total internal reflection is designated by TIR. This angle is found by use of Snell's law,

$$\frac{\cos \theta_1}{C_1} = \frac{\cos \theta_2}{C_2} \quad (3)$$

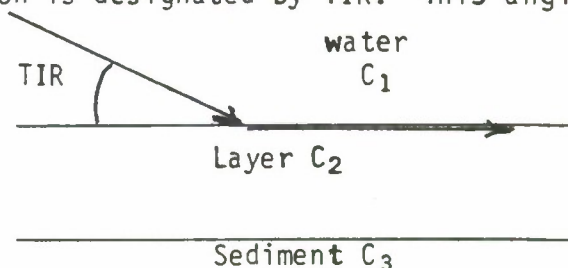


Figure 3. Ray Path for Total Internal Reflection

where  $C_1$  and  $C_2$  are speeds of sound at the bottom of water and in the layer respectively while  $\theta_1 = \text{TIR}$  is the grazing angle in the water at the water-layer interface and  $\theta_2 = 0$ , i.e. the refracted ray is parallel to the water-layer boundary. Thus  $\cos \text{TIR} = \frac{C_1}{C_2}$  and

$$\text{RATIO} = \frac{C_2}{C_1} = 1 / \cos \text{TIR}, \quad (4) \quad \text{if TIR is expressed in radians or}$$

$$\frac{C_2}{C_1} = 1 / \cos \left( \text{TIR} \times \frac{\pi}{180} \right) \quad (5) \quad \text{for TIR input}$$

in degrees. Then

$$C_2 = C_1 \times \text{RATIO} \quad (6)$$

and since it is assumed the sound goes into the sediment below the layer, the assumption is made that the speed of sound in the sediment below the layer is the same as in the layer so  $C_3 = C_2$ .

### IF GRADIENT G IS NOT SPECIFIED, CALCULATE IT FROM THE CAUSTIC ANGLE, THC

If  $G \neq 0$  go to 300

If  $\text{THC} \leq 0$  let  $\text{THC} = 30$  degrees. This is a starting estimate of the angle in degrees.

Call GCOMP (the last subroutine in the program).

# SUBROUTINE GCOMP

This subroutine is used to compute the sound speed gradient,  $g_o$ , at the top of the sediment. Quantities are defined as follows:

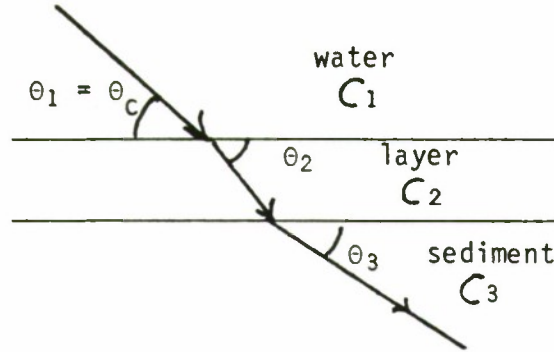


Figure 4. Ray path showing angle designations.

THRC = 30

THCØ = THC =  $\theta_c$

B = Beta

THRC = 30 X  $\pi/180$  converts angle to radians.

THINC = 1 an angle increment of 1 degree.

D1 = 2\*ZB-ZR-ZS is twice the effective depth,  $\bar{D}$ , given by equation (10) of Spofford et al.(1982).

$$TH3 = \Theta = \cos^{-1} \frac{C_3}{C_1} \cos \theta_c \quad \text{from Snell's law and figure 4.} \quad (7)$$

$$FACT\ 1 = F1 = \frac{2BC_3}{1+B} \quad (8)$$

$$FACT\ 2 = F2 = 1 + \frac{1}{2B} \left( 1 + \frac{\theta_3}{\sin \theta_3 \cos \theta_3} \right) \quad (9)$$



In order to obtain the equation for  $GZERO = g_0$  in the program, we need the equation for the range as given by equations (16) and (21) of Spofford et al. (1982) which can be obtained as follows:

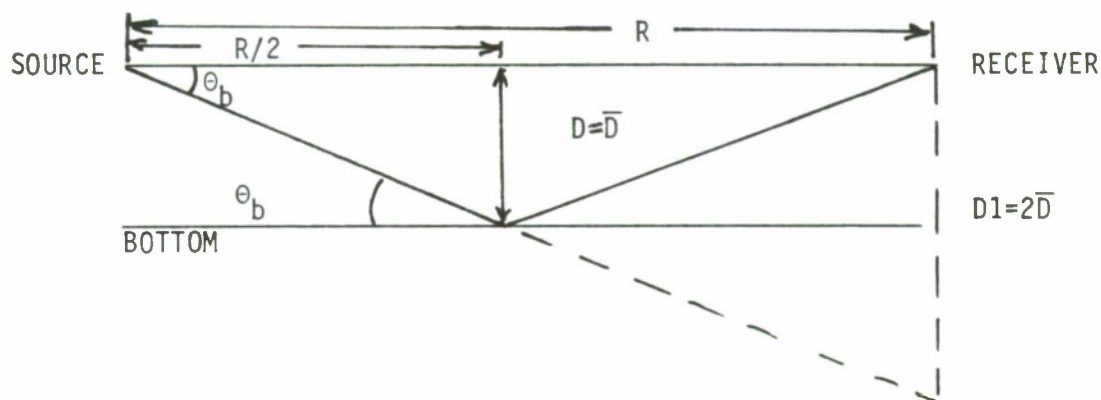


Figure 5. Diagram showing range, depth, and apparent bottom grazing angle relationship.

$$\tan \theta_b = \frac{D}{R/2} = \frac{2\bar{D}}{R} = \frac{D1}{R} \quad (10)$$

where  $D1 =$  twice the effective depth.

For sound refracted in the bottom, an increment,  $R_s$ , must be added as shown.

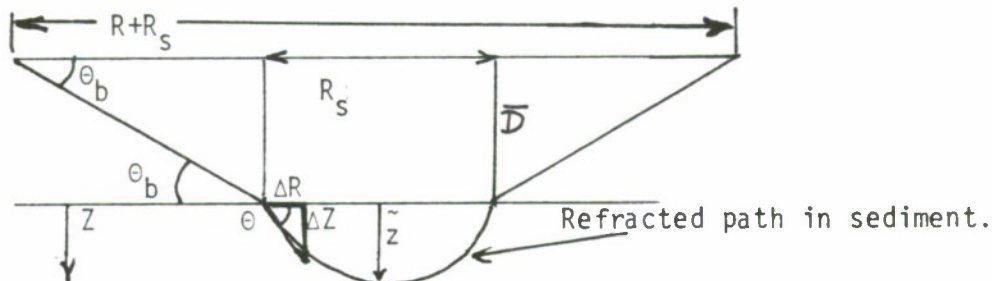


Figure 6. Range increment for refraction in sediment.

In the sediment  $\tan \theta = \frac{\Delta z}{\Delta R}$  so

$$(11) \quad dR = \frac{dz}{\tan \theta(z)} \quad \text{and eq. (16) of Spofford et al. (1982) is}$$

$$(12) \quad R_s = 2 \int_0^{\tilde{z}} \frac{dz}{\tan \theta(z)} \quad \text{where } \tilde{z} \text{ is either}$$

the turning point depth for the refracted ray, or the basement depth for rays which reflect from the basement. Snell's law applies in the sediment where the sound speed gradient is assumed to be vertical so (letting subscript 0 refer to the top of the sediment)

$$\cos \theta(z) = \frac{\cos \theta_0}{C_0} C(z) \quad (13)$$

and taking a

derivative with respect to  $z$  we get

$$-\sin \theta(z) \frac{d\theta(z)}{dz} = \frac{\cos \theta_0}{C_0} \frac{dC(z)}{dz} = \frac{\cos \theta_0}{C_0} g(z) \quad (14)$$

where  $g(z)$  is the sound speed gradient in the sediment.

$$\tan \theta(z) = \frac{\sin \theta(z)}{\cos \theta(z)} = \frac{(-\cos \theta_0 / C_0) g(z)}{(\cos \theta_0 / C_0) C(z) \left( \frac{d\theta(z)}{dz} \right)} \quad (15)$$

$$\tan \theta(z) = - \frac{g(z)}{C(z) \frac{d\theta(z)}{dz}} \quad (16)$$

$$\cot \theta(z) = C(z) \frac{d\theta}{dz} \quad (17)$$

$$R_s = 2 \int_0^{\tilde{z}} \cot \theta(z) dz = 2 \int_0^{\tilde{z}} \frac{C(z)}{g(z)} \frac{d\theta(z)}{dz} dz \quad (18)$$

In the model it is assumed  $g(z) = \frac{g_0(1+B)C_0}{C(z)+BC_0}$  and we have

$$C(z) = \frac{C_0 \cos \theta(z)}{\cos \theta_0} \quad \text{so} \quad (19)$$

$$\frac{C(z)}{g(z)} = \frac{C_0 \cos \theta(z)}{\cos \theta_0} \left( \frac{C(z) + BC_0}{g_0(1+B)C_0} \right) \quad (20)$$

$$= \frac{BC_0 \cos \theta(z)}{g_0(1+B) \cos \theta_0} + \frac{C(z) \cos \theta(z)}{g_0(1+B) \cos \theta_0} \quad (21)$$

$$= \frac{BC_0 \cos \theta(z)}{g_0(1+B) \cos \theta_0} + \frac{C_0 \cos^2 \theta(z)}{g_0(1+B) \cos^2 \theta_0} \quad (22)$$

$$= \frac{C_0}{g_0(1+B) \cos \theta_0} \left[ \frac{B \cos \theta(z)}{1} + \frac{\cos^2 \theta(z)}{\cos \theta_0} \right] \quad (23)$$

Changing variable for integration from  $z$  to  $\theta$  gives

$$R_S = \frac{-2C_0}{g_0(1+B)\cos\theta_0} \int_{\theta_0}^{\theta'} \left[ B \cos\theta(z) + \frac{\cos^2\theta(z)}{\cos\theta_0} \right] d\theta. \quad (24)$$

Interchanging limits changes the sign to give upon integration.

$$R_S = \frac{2C_0}{g_0(1+B)\cos\theta_0} \left[ B \sin\theta + \left( \frac{\theta}{2} + \frac{\sin 2\theta}{4} \right) \frac{1}{\cos\theta_0} \right]_{\theta=\theta_0}^{\theta=\theta'}, \quad (25)$$

$$R_S = \frac{C_0}{g_0(1+B)\cos\theta_0} \left[ 2B \sin\theta + \frac{\theta}{\cos\theta_0} + \frac{\sin\theta \cos\theta}{\cos\theta_0} \right]_{\theta=\theta_0}^{\theta=\theta'}. \quad (26)$$

Letting  $\theta' = 0$  in this equation for a path refracted in the sediment without reaching the basement gives

$$R = \frac{2D}{\tan\theta_b} + \frac{C_0}{g_0(1+B)\cos\theta_0} \left[ \frac{\theta_0}{\cos\theta_0} + \sin\theta_0(1+2B) \right]. \quad (27)$$

Now substitute as follows:  $2D = D1$ ,  $\theta_b = \theta_{rc} = \text{THRC}$ ,  $\theta_0 = \theta_3$  and find with  $C_0 = C_3$

$$R = \frac{D1}{\tan\theta_{rc}} + \frac{C_3 \sin\theta_3}{g_0(1+B)\cos\theta_3} \left[ \frac{\theta_3}{\sin\theta_3 \cos\theta_3} + (1+2B) \right], \quad (28)$$

$$R = \frac{D1}{\tan\theta_{rc}} + \frac{2BC_3 \tan\theta_3}{g_0(1+B)(2B)} \left[ (2B+1) + \frac{\theta_3}{\sin\theta_3 \cos\theta_3} \right], \quad (29)$$

$$R = \frac{D1}{\tan\theta_{rc}} + \left( \frac{2BC_3}{1+B} \right) \left( \frac{\tan\theta_3}{g_0} \right) \left[ 1 + \frac{1}{2B} + \frac{\theta_3}{2B \sin\theta_3 \cos\theta_3} \right], \quad (30)$$

$$R = \frac{D1}{\tan\theta_{rc}} + \frac{F_1 F_2 \tan\theta_3}{g_0}. \quad (31)$$

This is the same as the equation for  $R$  in the program. Take the derivative of  $R$  with respect to  $\theta_3$  which can then be set equal to zero since we expect

$\frac{dR}{d\theta_3} = 0$  for the caustic ray.

$$\frac{dR}{d\theta_3} = -D1 \csc^2\theta_{rc} \frac{d\theta_{rc}}{d\theta_3} + \frac{F_1}{g_0} \left[ \left( \frac{dF_2}{d\theta_3} \right) \tan\theta_3 + F_2 \sec^2\theta_3 \right] = 0 \quad (1)$$

Find  $\frac{d\theta_{rc}}{d\theta_3}$  as follows:



$$\text{Snell's law is } \cos \theta_{rc} = \frac{C_1}{C_3} \cos \theta_3, \quad (33)$$

and taking a derivative gives

$$-\sin \theta_{rc} \frac{d\theta_{rc}}{d\theta_3} = -\frac{C_1}{C_3} \sin \theta_3, \quad (34)$$

$$\frac{d\theta_{rc}}{d\theta_3} = \frac{C_1}{C_3} \frac{\sin \theta_3}{\sin \theta_{rc}}, \text{ and} \quad (35)$$

$$\frac{dF_2}{d\theta_3} = \frac{1}{2B} \left[ \frac{1}{\sin \theta_3 \cos \theta_3} + \frac{\theta_3 \sec \theta_3 \tan \theta_3}{\sin \theta_3} - \frac{\theta_3 \csc \theta_3 \cot \theta_3}{\cos \theta_3} \right]. \quad (36)$$

By use of identities we can write

$$\frac{dF_2}{d\theta_3} = \frac{1}{2B \sin \theta_3 \cos \theta_3} \left[ 1 + \theta_3 \left( \frac{\sin^2 \theta_3 - \cos^2 \theta_3}{\sin \theta_3 \cos \theta_3} \right) \right]. \quad (37)$$

Substitution of (2) and (3) into (1) gives

$$-D_1 \csc^2 \theta_{rc} \left( \frac{C_1}{C_3} \right) \frac{\sin \theta_3}{\sin \theta_{rc}} + \frac{F_1}{g_0} \left\{ \frac{\tan \theta_3}{2B \sin \theta_3 \cos \theta_3} \right. \quad (38)$$

$$\times \left[ 1 + \theta_3 \left( \frac{\sin^2 \theta_3 - \cos^2 \theta_3}{\sin \theta_3 \cos \theta_3} \right) \right] + F_2 \sec^2 \theta_3 \left. \right\} = 0. \quad (39)$$

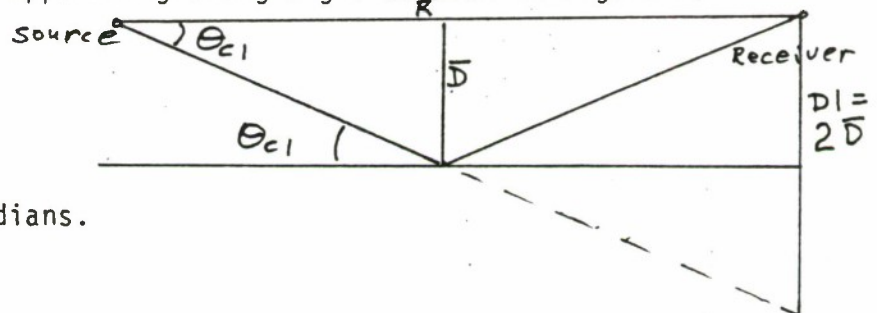
Solving this equation for  $g_0$  and using some identities gives the result

$$g_0 = \left( \frac{C_3 \sin^2 \theta_{rc}}{C_1 D_1 \sin \theta_3} \right) \left\{ \frac{C_3}{(1+B) \cos^2 \theta_3} \left[ 1 - \theta_3 \left( \frac{\cos^2 \theta_3 - \sin^2 \theta_3}{\sin \theta_3 \cos \theta_3} \right) \right] + \frac{F_1 F_2}{\cos^2 \theta_3} \right\}. \quad (40)$$

which is the same as the equation in the program for the sound speed gradient at the top of the sediment GZERO.

The program follows an iterative procedure as follows:

$$\text{THC1} = \theta_{c1} = \tan^{-1} \frac{D_1}{R} = \text{apparent grazing angle as seen in Figure 7.}$$



THC1 is converted to radians.

Figure 7. Apparent grazing angle.

MAXIT = 100 is maximum number of iterations beginning with computations of  $g_0$  and R for THRC = 30. Then THRC is incremented by 1 degree, converted to radians, TH3 is computed from Snell's law and new values of  $g_0$ , R, and THC2 are computed.

If  $|THC0-THC| \leq .01$ , the computation is finished and  $THC=THC2$ . Otherwise iterations continue with the increment changing sign and being divided by 2 until convergence occurs. When convergence is obtained, the output is printed:

THC = THC2 and

G = GZERO.

Nonconvergence is indicated by the output statement  
ITERATIONS AND STILL NO SOLUTION.

RETURN

END (of Subroutine GCOMP)

Write statements start printout

CHANGE DEGREES TO RADIANS

THETA } This is done for these angles.  
THC }  
TIR }

CALL ROUTINE WHICH CALCULATES THE REMAINING GEOPHYSICAL PARAMETERS FROM THE  
INVERSION INPUTS

CALL GEOPHYS

#### SUBROUTINE GEOPHYS

COMPUTE DENSITIES RH2, RH3

$$Z_1 = C_1 P_1 \quad (41)$$

$$D = \frac{C_1}{4FM} = \frac{\lambda_2}{4} = \text{quarter wavelength in layer at top of sediment.} \quad (42)$$

Note: speed of sound in the layer,  $C_2$ , should be used here instead of speed of sound in water,  $C_1$ , in order to get the correct layer thickness D.

$$R = \text{EXP}(-\text{ALOG}(10) * \text{ALOSS}\emptyset / 20) \text{ can be written} \quad (43)$$

$$R = \exp(-\ln 10) \frac{\text{ALOSS}\emptyset}{20} \quad (44)$$

We can see this as follows:

The reflection coefficient  $R = (\text{pressure of reflected wave}) / (\text{pressure of incident wave})$ . Thus  $\text{ALOSS}\emptyset = -20 \log_{10} R$  is the low frequency loss levels at high angles.

$$\frac{-\text{ALOSS}\emptyset}{20} = \log_{10} R = \frac{\ln R}{\ln 10} \quad (45)$$

$$\ln R = -(\ln 10) \frac{\text{ALOSS}\emptyset}{20} \quad \text{Then e raised to power } \ln R \text{ gives the equation}$$

for R.

$Z_3 = (1+R)/(1-R)Z_1$ . This is the impedance  $Z_3$  of a medium into which a wave (46) is traveling from another medium which has impedance  $Z_1$  and is given by eq. (2.14) of Brekhovskikh(1980) with subscripts changed to correspond to our situation. Normal incidence as assumed.

$$-(\ln 10) \frac{\text{ALOSSM}}{20} \quad (47)$$

$$R = e$$

$\text{ALOSSM}$  is the minimum loss level at high angles. This should occur when the layer thickness  $D = \lambda/4$ . For these conditions according to eq. (3.23) of Brekhovshikh(1980),

$$R = \frac{Z_2^2 - Z_1 Z_3}{Z_2^2 + Z_1 Z_3} \quad (48)$$

If  $\text{ALOSSM}$  is a minimum, then  $R$  is a maximum. When  $R$  is maximum, then  $Z_2$  is greater than  $Z_1$  and  $Z_3$  and we have a high acoustical impedance layer which acts as a good sound reflector. If the value of  $Z_2$  is between those of  $Z_1$  and  $Z_3$  we have good transmission and a small reflection coefficient. When

$Z_2 = \sqrt{Z_1 Z_3}$ ,  $R=0$  and the incident ray is completely transmitted. In this (49) case there is no minimum value of loss at a particular frequency for high angles. Solve the equation for  $Z_2$ .



$$R Z_2^2 + R Z_1 Z_3 = Z_2^2 - Z_1 Z_3 \quad (50)$$

$$Z_2^2 (R-1) = -Z_1 Z_3 (R+1) \quad (51)$$

$$Z_2 = \sqrt{\frac{1-R}{1+R} Z_1 Z_3} \quad (52)$$

in agreement with the second expression for  $Z_2$  in this subroutine.

$$SPRAT = C_3/C_1 \text{ is the sound speed ratio.} \quad (53)$$

$$RH2 = \rho_2 = \frac{Z_2}{C_2} \text{ is the density in the layer.} \quad (54)$$

$$RH3 = \rho_3 = \frac{Z_3}{C_3} \text{ is the density in the sediment.} \quad (55)$$

COMPUTE DISSIPATION CONSTANT ALPHA

$$THETA = \cos^{-1} \frac{C_2}{C_1} \cos(THETA) = \theta_2 \text{ is the angle in the layer corresponding to } (56)$$

the bottom grazing angle THETA which is input data. The sound speed  $C_2$  is assumed to be the speed at the top of the sediment as well as in the layer.

$$BS = \sin \theta_2 \quad (57)$$

$$BC = \cos \theta_2 \quad (58)$$

$$V_{32} = \frac{Z_3 - Z_2}{Z_3 + Z_2} \text{ used to calculate the layer reflection.} \quad (59)$$

$$V_{21} = \frac{Z_2 - Z_1}{Z_2 + Z_1} \text{ and transmission coefficients. These represent equations (31) (60)}$$

and (32) respectively of Spofford et al. (1982)..

$$AUX = \frac{4\pi D F}{C_1} \sin \theta_2 = \delta \text{ gives twice the phase length for propagation of a wave } (61)$$

through the layer as is shown below. Note:  $C_1$  should be changed to  $C_2$ , the speed of sound in the layer, in the last expression for AUX.

$$V = \left| \frac{V_{21} + V_{32} (\cos \delta + i \sin \delta)}{1 + V_{21} V_{32} (\cos \delta + i \sin \delta)} \right| \quad (62)$$

This is the reflection coefficient for a plane layer. It corresponds to equation (3.20) of Brekhovskikh (1980) with appropriate changes in subscripts giving equation (30) of Spofford et al. (1982) and use of the relation

$$\cos \delta + i \sin \delta = e^{i\delta}.$$

$$T = \frac{16 Z_1 Z_3 \left( \frac{Z_2}{(Z_1 + Z_2)(Z_2 + Z_3)} \right)^2}{[1 + V_{21} V_{32} (\cos \delta + i \sin \delta)]^2} \quad (63)$$

This is a two-way transmission coefficient. It corresponds to the use of the transmission coefficient equation (3.21) of Brekhovskikh (1980) two times; once for transmission from water (1), to layer (2), to sediment (3), and once for transmission from sediment (3), to layer (2), to water (1).

For a wave propagating downward, we have from equation (3.21) of Brekhovskikh(1980)

$$W = \frac{4Z_1 Z_2}{(Z_1 + Z_2)(Z_2 + Z_3)} \times \frac{1}{e^{-ik_{22}d} + V_{32}V_{21}e^{ik_{22}d}} \quad (64)$$

Taking account of coordinate axis directions and layer numbering for our case we should have

$$W \rightarrow T_1 = \frac{4Z_3 Z_2}{(Z_3 + Z_2)(Z_2 + Z_1)} \frac{1}{e^{i\alpha} + V_{12}V_{23}e^{-i\alpha}} \quad (65)$$

and for a wave traveling upward

$$T_2 = \frac{4Z_1 Z_2}{(Z_1 + Z_2)(Z_2 + Z_3)} \frac{1}{e^{-i\alpha} + V_{23}V_{12}e^{i\alpha}} \quad (66)$$

The two-way layer transmission coefficient is then the product

$$T = T_1 T_2 = 16Z_1 Z_3 \left( \frac{Z_2}{(Z_1 + Z_2)(Z_2 + Z_3)} \right)^2 \times \frac{1}{\left( e^{i\alpha} + V_{12}V_{23}e^{-i\alpha} \right) \left( e^{-i\alpha} + V_{32}V_{21}e^{i\alpha} \right)} \quad (67)$$

$$T = 16Z_1 Z_3 \left( \frac{Z_2}{(Z_1 + Z_2)(Z_2 + Z_3)} \right)^2 \frac{1}{1 + V_{32}V_{21}(e^{i2\alpha} + e^{-i2\alpha}) + (V_{32}V_{21})^2} \quad (68)$$

$$T = \frac{16Z_1 Z_3 \left( \frac{Z_2}{(Z_1 + Z_2)(Z_2 + Z_3)} \right)^2}{1 + 2V_{32}V_{21}\cos 2\alpha + (V_{32}V_{21})^2} \quad (69)$$

where

$$\alpha = k_{22}d = k_2 d \sin \theta_2 = \frac{2\pi FD}{C_2} \sin \theta_2 \quad (70)$$

the phase length for travel through the layer, and we see

$$AUX = \frac{4\pi FD \sin \theta_2}{C_1} = 2\alpha = \delta, \text{ the expression in the } (71)$$

subroutine. Note  $C_1$  should be changed to  $C_2$  here.

The denominator of  $T$  given in the subroutine is the same as in the last expression for  $T$ . Sign changes of the  $Z$ 's due to changes of direction which might be troublesome cancel out.



$$AUX = \frac{10^{-DBLOSS/10} - V^2}{T} \quad (72)$$

$$ALS = -10 \log_{10} \left( \frac{10^{-DBLOSS/10} - V^2}{T} \right) = DL. \quad (73)$$

We can arrive at this relation by starting with the assumption that losses behave linearly in sediments as expressed by equation (13) of Spofford et al. (1982)

$L = K \cdot S \cdot f_k$  where  $K$  is the absorption coefficient,  $S$  is path length, and  $f_k$  is frequency.

This can be rewritten in integral form. From Snell's law and differentiation we find

$$\cos \theta(z) = \frac{\cos \theta_0}{C_0} C(z), \text{ and} \quad (74)$$

$$- \sin \theta(z) \frac{d\theta(z)}{dz} = \frac{\cos \theta_0}{C_0} g(z), \text{ where } g(z) = \frac{dC(z)}{dz}, \quad (75)$$

$$DL = -2 \int_0^z \frac{C_0 f_k (k_0 + k'_0 z)}{\cos \theta_0 g(z)} dz \left( \frac{d\theta}{dz} \right). \text{ Using } g(z) = \frac{g_0 (1+B) C_0}{C(z) + B C_0} \quad (76)$$

$$DL = \frac{-2 C_0 f_k}{g_0 (1+B) C_0 \cos \theta_0} \int_0^z (k_0 + k'_0 z) (C(z) + B C_0) \frac{d\theta}{dz} dz, \quad (77)$$

$$DL = \frac{-2 f_k}{g_0 (1+B) \cos \theta_0} \int_{\theta_0}^{\theta'} [k_0 C(z) + k'_0 z C(z) + B k_0 C_0 + k'_0 B C_0 z] d\theta \quad (78)$$

The sound speed profile for the model is assumed to be, as given by equation (13) of Spofford et al. (1982):

$$C(z) = [2 g_0 (1+B) C_0 z + (1+B)^2 C_0^2]^{\frac{1}{2}} - B C_0, \quad (79)$$

from which

$$(C + B C_0)^2 = 2 g_0 (1+B) C_0 z + (1+B)^2 C_0^2, \quad (80)$$

$$(C + B C_0)^2 - (1+B)^2 C_0^2 = 2 g_0 (1+B) C_0 z, \quad (81)$$

$$z = \frac{(C + B C_0)^2 - (1+B)^2 C_0^2}{2 g_0 (1+B) C_0} = \frac{(C + B C_0)^2 - (1+B)^2 C_0^2}{2 \sigma} \quad (82)$$

where

$$\sigma = g_0 (1+B) C_0 \quad (83)$$

Substituting Z into the equation for DL gives

$$DL = \frac{-2fk}{g_0(1+B)\cos\theta_0} \int_{\theta_0}^{\theta'} \left\{ \frac{k_0 C_0 \cos\theta}{\cos\theta_0} + \frac{k_0' C_0 \cos\theta}{2\sigma \cos\theta_0} \left[ \left( \frac{C_0 \cos\theta}{\cos\theta_0} + BC_0 \right)^2 - (1+B)^2 C_0^2 \right] \right. \\ \left. + Bk_0 C_0 + \frac{BC_0 k_0'}{2\sigma} \left[ \left( \frac{C_0 \cos\theta}{\cos\theta_0} + BC_0 \right)^2 - (1+B)^2 C_0^2 \right] \right\} d\theta \quad (84)$$

$$\text{Let } D = \frac{-2fk}{g_0(1+B)\cos\theta_0}$$

$$DL = D \int_{\theta_0}^{\theta'} \left\{ \frac{k_0 C_0 \cos\theta}{\cos\theta_0} + \frac{k_0' C_0 \cos\theta}{2\sigma \cos\theta_0} \left[ \frac{C_0^2 \cos^2\theta}{\cos^2\theta_0} + \frac{2BC_0^2 \cos\theta}{\cos\theta_0} + BC_0^2 \right. \right. \\ \left. \left. - C_0^2 - 2BC_0^2 - B^2 C_0^2 \right] + Bk_0 C_0 \right. \\ \left. + \frac{BC_0 k_0'}{2\sigma} \left[ \frac{C_0^2 \cos^2\theta}{\cos^2\theta_0} + \frac{2BC_0^2 \cos\theta}{\cos\theta_0} + BC_0^2 - C_0^2 - 2BC_0^2 - B^2 C_0^2 \right] \right\} d\theta \quad (85)$$

$$DL = C_0 D \int_{\theta_0}^{\theta'} \left\{ \frac{k_0 \cos\theta}{\cos\theta_0} + \frac{k_0' C_0^2}{2\sigma \cos\theta_0} \left[ \frac{\cos^3\theta}{\cos^2\theta_0} + \frac{2B \cos^2\theta}{\cos\theta_0} - (1+2B) \cos\theta \right] \right. \\ \left. + Bk_0 + \frac{BC_0^2 k_0'}{2\sigma} \left[ \frac{\cos^2\theta}{\cos^2\theta_0} + \frac{2B \cos\theta}{\cos\theta_0} - (1+2B) \right] \right\} d\theta \quad (86)$$

$$DL = C_0 D \left[ \frac{k_0 \sin\theta}{\cos\theta_0} + \frac{k_0' C_0^2}{2\sigma \cos\theta_0} \left\{ \frac{1}{\cos^2\theta_0} \left( \sin\theta - \frac{\sin^3\theta}{3} \right) + \frac{2B}{\cos\theta_0} \left( \frac{\theta}{2} + \frac{\sin 2\theta}{4} \right) \right. \right. \\ \left. \left. - (1+2B) \sin\theta + Bk_0 \theta \right. \right. \\ \left. \left. + \frac{BC_0^2 k_0'}{2\sigma} \left\{ \frac{1}{\cos^2\theta_0} \left( \frac{\theta}{2} + \frac{\sin 2\theta}{4} \right) + \frac{2B}{\cos\theta_0} \sin\theta - (1+2B) \theta \right\} \right] \right]_{\theta_0}^{\theta'} \quad (87)$$

Interchanging the limits of integration and factoring gives

$$DL = \frac{2C_0 f k}{g_0 (1+B) \cos \theta_0} \left[ \left( \sin \theta - \frac{\sin^3 \theta}{3} \right) \frac{k_0' C_0^2}{2\sigma \cos^3 \theta_0} \right. \\ + \left( \frac{\theta + \sin \theta \cos \theta}{2} \right) \left( \frac{2B C_0^2 k_0' + B C_0^2 k_0'}{2\sigma \cos^2 \theta_0} \right) \\ + (\sin \theta) \left( \frac{2\sigma k_0 - (1+2B) k_0' C_0^2 + 2B^2 C_0^2 k_0'}{2\sigma \cos \theta_0} \right) \\ \left. + (\theta) \left( B k_0 - \frac{B C_0^2 k_0' (1+2B)}{2\sigma} \right) \right]_{\theta'}^{\theta_0} \quad (88)$$

This is equation (23) of Spofford et al. (1982). Note that in the second line of equation (23) of Spofford et al. (1982) the power of  $\cos \theta_0$  should be 2 instead of 4. Now consider figure 8.

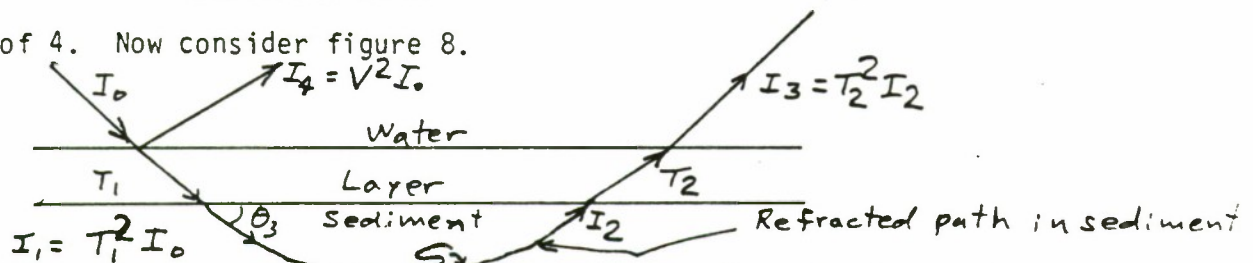


Figure 8. Intensity Relationships for reflected and refracted paths.

Loss due to attenuation in the sediment only is

$$DL = -10 \log_{10} \frac{I_2}{I_1} \quad (89)$$

We see  $I_1 = T_1^2 I_0$  and

$I_3 = T_2^2 I_2$  where  $T_1$  and  $T_2$  are transmission coefficients defined previously. The intensity of the reflected ray

$I_4 = V^2 I_0$  where  $V$  is the layer reflection coefficient defined previously. The intensity of the sound leaving the bottom after reflection

from and transmission through the layer is

$$I_5 = I_3 + I_4 \quad (90)$$

$$I_5 = T_2^2 I_2 + V^2 I_0 \quad (91)$$

$$\frac{I_5}{I_0} = V^2 + (T_2^2 / I_0) I_2 \quad (92)$$

An expression for  $I_2$  is needed.

$$\text{Now } 10 \log I_2 = 10 \log I_1 - DL, \quad (93)$$

$$\log I_2 = \log I_1 - DL/10, \quad (94)$$

$$I_2 = \text{antilog}(\log I_1 - DL/10). \quad (95)$$

$$\text{Thus } \frac{I_5}{I_0} = V^2 + (T_2^2/I_0) \text{antilog}(\log I_1 - DL/10), \quad (96)$$

$$\frac{I_5}{I_0} = V^2 + (T_2^2/I_0) \text{antilog}(\log T_1^2 I_0 - DL/10). \quad (97)$$

$$\text{The measured loss } DBL_{LOSS} = -10 \log \frac{I_5}{I_0}, \quad (98)$$

$$-DBL_{LOSS}/10 = \log[V^2 + (T_2^2/I_0) \text{antilog}(\log T_1^2 I_0 - DL/10)] \quad (99)$$

$$\text{Note that } 10^{-DBL_{LOSS}/10} = V^2 + (T_2^2/I_0) \text{antilog}(\log T_1^2 I_0 - DL/10) \quad (100)$$

$$10^{-DBL_{LOSS}/10} - V^2 = (T_2^2/I_0) \text{antilog}(\log T_1^2 I_0 - DL/10) \quad (101)$$

$$\log \left( I_0 \frac{10^{-DBL_{LOSS}/10} - V^2}{T_2^2} \right) = \log T_1^2 I_0 - DL/10 \quad (102)$$

$$\log \frac{10^{-DBL_{LOSS}/10} - V^2}{T_1^2 T_2^2} = -DL/10, \quad \text{Let } T_1 T_2 = T. \quad (103)$$

$$\text{Now } DL = -10 \log_{10} \frac{10^{-DBL_{LOSS}/10} - V^2}{T} = ALS \quad (104)$$

as given by the expression in the program. Note that this denominator should be changed to  $T^2$  to agree with the preceding equation.

Equation (23) of Spofford et al. (1982) for the dissipation loss

in the sediment can be rewritten in terms of frequency  $FK$  in kHz,  $SIG = \sigma$ ,

$AMU = \mu$ ,  $ANU = \nu$ ,  $ALPH0 = \alpha_0 = k_0$ , and  $GAM = \gamma$  as expressed in the program as

$$\begin{aligned} \frac{DL}{FK} = & \frac{2C_2}{g_0(1+B)\cos\theta_2} \left[ \frac{\gamma C_2^2}{2\sigma \cos^3\theta_2} \left( \sin\theta_2 - \frac{\sin^3\theta_2}{3} \right) \right. \\ & + \left( \frac{B\gamma C_2^2 + 2\gamma\nu C_2}{4\sigma \cos^2\theta_2} \right) \left( \theta_2 + \sin\theta_2 \cos\theta_2 \right) \\ & + \left( \frac{\gamma(\nu^2 - \mu) + 2B\gamma\nu C_2}{2\sigma \cos\theta_2} \right) \sin\theta_2 + \frac{B\gamma(\nu^2 - \mu)}{2\sigma} \theta_2 \left. \right] \\ & + \alpha_0 \left( \frac{\sin\theta_2}{\cos\theta_2} + B\theta_2 \right) \frac{2C_2}{g_0(1+B)\cos\theta_2}, \end{aligned} \quad (105)$$



where  $\theta' = 0$ ,  $\theta_2 = \theta_0$  the grazing angle of the ray in the layer with the top of the sediment,  $\gamma = k_0'$  the gradient of the absorption coefficient and  $\alpha_0 = k_0$ .

Solving for  $\alpha_0$  we obtain as in the subroutine

$$\alpha_0 = \frac{A L S}{F_k} - \frac{2 C_2}{g_0 (1+B) \cos \theta_2} \left[ \frac{\gamma C_2^2}{2 \sigma \cos^3 \theta} \left( \sin \theta_2 - \frac{\sin^3 \theta_2}{3} \right) + \left( \frac{B \gamma C_2^2 + 2 \gamma \gamma C_2}{4 \sigma \cos^2 \theta_2} \right) (\theta_2 + \sin \theta_2 \cos \theta_2) + \left( \frac{\gamma (\gamma^2 - \mu) + 2 B \gamma \gamma C_2}{2 \sigma \cos \theta_2} \right) \sin \theta_2 + \frac{B \gamma (\gamma^2 - \mu) \theta_2}{2 \sigma} \right] \times \left( \frac{g_0 (1+B) \cos \theta_2}{2 C_2} \right) \left( \frac{\sin \theta_2}{\cos \theta_2} + B \theta_2 \right)^{-1} \quad (106)$$

which is the equation for the dissipation constant at the top of the sediment.

For this computation, it is assumed that the speed,  $C_2$ , and angle,  $\theta_2$  are the same in the layer and at the top of the sediment. Also, note that  $F_k$  is the center frequency of a one-octave frequency band used for processing measured data.

RETURN

END (of SUBROUTINE GEOPHYS)

GO TO 499.

499 CALL CANGLE

#### SUBROUTINE CANGLE

D1=2ZB-ZR-ZS is twice the effective depth,  $\bar{D}$ , given by equation (10) of Spofford et al.(1982).

#### CALCULATE SEDIMENT THICKNESS

B = beta

CZP = 2000

Sound speed at the top of the sediment is assumed to be  $C_2$ . The equation for one-way travel time in the sediment is needed. The necessary equation can be derived by assuming the sound is propagating downward in the Z direction.

By definition  $C(z) = \frac{dz}{dt}$  so (107)

$dt = \frac{dz}{C(z)}$  and (108)

$t = \int \frac{dz}{C(z)}$  (109)

The sound speed gradient in the sediment is given by the model as

$$g = \frac{dc}{dz} = \frac{g_0 (1+B)C_2}{C + BC_2} \quad (110)$$

$$\text{Let } \sigma = \frac{g_0 (1+B)C_2}{C + BC_2} \text{ Then} \quad (111)$$

$$dz = \frac{(C + BC_2)}{g_0 (1+B)C_2} dC = \frac{(C + BC_2) dC}{\sigma} \quad (112)$$

$$t = \frac{1}{\sigma} \int_{C_2}^{C(z)} \frac{C + BC_2}{C} dC \quad (113)$$

$$t = \frac{1}{\sigma} \int_{C_2}^{C(z)} \left( 1 + B \frac{C_2}{C} \right) dC = \frac{1}{\sigma} \left[ C + BC_2 \ln C \right]_{C_2}^{C(z)} \quad (114)$$

$$t = \frac{1}{\sigma} \left[ C(z) + BC_2 \ln C(z) - C_2 - BC_2 \ln C_2 \right] \quad (115)$$

$$t = \frac{1}{\sigma} \left[ C(z) - C_2 + BC_2 \ln \frac{C(z)}{C_2} \right] \quad (116)$$

$$t = \frac{C_2}{\sigma} \left[ \frac{C(z)}{C_2} - 1 + B \ln \frac{C(z)}{C_2} \right] \quad (117)$$

$$t = \frac{1}{g_0 (1+B)} \left[ \left( \frac{C(z)}{C_2} - 1 \right) + B \ln \frac{C(z)}{C_2} \right] \quad (118)$$

This is the one-way travel time for sound in the sediment and is equation (3)

in "DOCUMENTATION OF BOTTOM LOSS UPGRADE PARAMETERS." This equation cannot

be solved in closed form for depth of sediment  $BZ=z$  so we will find  $C(z)$  at

the bottom of the sediment (basement depth) by use of Newton's method of

approximating a root and use  $C(z)$  to find  $z$ . From the last equation

$$g_0 (1+B)t = \frac{C(z)}{C_2} - 1 + B \ln C(z) - B \ln C_2 \quad (119)$$

$$C_2 g_0 (1+B)t = C(z) - C_2 + BC_2 \ln C(z) - BC_2 \ln C_2 \quad (120)$$

$$C_2 [g_0 (1+B)t + 1 - B \ln C_2] = C(z) + BC_2 \ln C(z) \quad (121)$$

Thus, in the subroutine we find

$$A = C_2 [g_0 (1+B)t + 1 - B \ln C_2] \quad (122)$$

as on the left side of the previous equation.

The formula for Newton's method is

$$A_1 = A - \frac{f(A)}{f'(A)} \text{ where } A \text{ is an approximation and } A_1 \text{ is an improved } (123)$$

value. Let  $A = CZP$  and  $A_1 = CZ$ , then

$$CZ = CZP - \frac{f(CZP)}{f'(CZP)} \text{ where} \quad (124)$$

$$f(CZP) = A - CZP - BC_2 \ln CZP \quad \text{and} \quad (125)$$

$$f'(CZP) = -1 - \frac{BC_2}{CZP} \text{ gives the result} \quad (126)$$

$$CZ = CZP + \frac{(A - CZP - BC_2 \ln CZP)}{1 + \frac{BC_2}{CZP}} \quad (127)$$

as in the subroutine. Starting with  $CZP = 2000$  as a first approximation, iterations continue until convergence is completed. This is chosen to occur (as in the subroutine)

$$\text{IF } |CZ - CZP| < .01, \text{ let}$$

$$CZP = CZ = C(z).$$

$$\text{From the formula } g = \frac{dC}{dz} = \frac{g_0(1+B)C_2}{C + BC_2} \quad (128)$$

we find  $Z$  by integration to be

$$Z = \int dz \quad (129)$$

$$Z = \int_{C_2}^{CZ} \frac{C + BC_2}{g_0(1+B)C_2} dC, \quad (130)$$

$$Z = \frac{1}{g_0(1+B)C_2} \int_{C_2}^{CZ} (C + BC_2) dC, \quad (131)$$

$$Z = \frac{1}{g_0(1+B)C_2} \left[ \frac{C^2}{2} + BC_2 C \right]_{C_2}^{CZ}, \quad (132)$$

$$Z = \frac{1}{g_0(1+B)C_2} \left[ \frac{(CZ)^2}{2} + \frac{2BC_2 CZ}{2} - \frac{C_2^2}{2} - \frac{2BC_2^2}{2} \right], \quad (133)$$

$$Z = \frac{1}{g_0(1+B)C_2} \left[ (CZ)^2 + 2BC_2 CZ + B^2 C_2^2 - C_2^2 - 2BC_2^2 - B^2 C_2^2 \right]. \quad (134)$$

$$70 \quad BZ = Z = \frac{1}{g_0(1+B)C_2} \left[ (CZ + BC_2)^2 - C_2^2(1+B)^2 \right], \quad (135)$$

as in the subroutine, gives the sediment thickness.

COMPUTE REFINED CRITICAL ANGLE THRC =  $\pi/4$

CALL TOTCRIT

SUBROUTINE TOTCRIT

Check that  $C_3 < C_2$

This insures that if total internal reflection occurs, it will be from the top of the (high speed) layer and the layer is distinct from the sediment beneath.

IF ( $C_3 \leq C_2$ ) GO TO 10 (where angle is computed)

Print format "C3 MUST BE LESS THAN OR EQUAL TO C2"

COMPUTE TIR = ANGLE OF TOTAL INTERNAL REFLECTION

TIR = 0

If  $C_2 \leq C_1$  GO TO 100. In this case TIR is not calculated. For total internal reflection, it is required that  $C_2 > C_1$ .

$$TIR = \cos^{-1} \frac{C_1}{C_2} \quad (136)$$

from Snell's law when refracted ray angle = 0.

100 CONTINUE.

COMPUTE THC = CRITICAL ANGLE (CAUSTIC).

This is done by an iterative procedure. Start with definitions as follows:

$$PI2 = \pi/2 \quad (137)$$

$$DELT = \pi/100 \quad (138)$$

$$D1 = 2ZB - ZR - ZS = 2\bar{D}, \text{ twice average depth of water below source and receiver} \quad (139)$$

$$D2 = \frac{2C_3 B}{90(1+B)} \quad (140)$$

$$FAC = C_3/C_1 \quad (141)$$

$$TH3 = \cos^{-1} \frac{C_3}{C_1} \text{ THRC} = \cos^{-1} \frac{C_3}{C_1} \Theta_{rc} = \Theta_3 \quad (142)$$

as in figure 9.

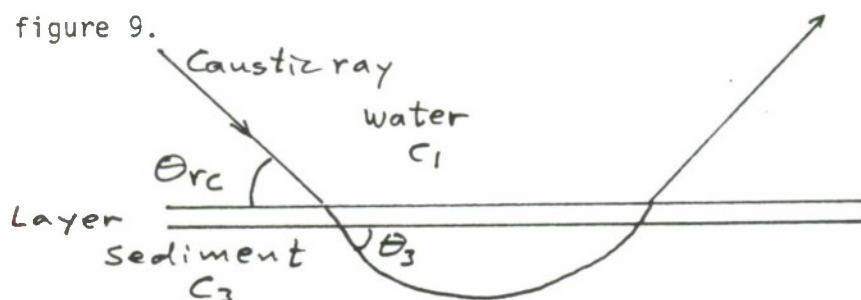


Figure 9. Angles for the caustic ray are illustrated.



For the first approximation use  $\theta_{rc} = \pi/4$ .

An approximate range is found by using  $\theta_{rc}$  and  $\theta_3$  in the range equation found by combining equations (16) and (21) of Spofford et al. (1982).

$$R = \frac{D1}{\tan \theta_{rc}} + \frac{2BC_3 \tan \theta_3}{g_0(1+B)} \left[ 1 + \left( 1 + \frac{\theta_3}{\sin \theta_3 \cos \theta_3} \right) \frac{1}{2B} \right] \quad (143)$$

Here the lower limit in the equation is zero.

$$R = \frac{D1}{\tan \theta_{rc}} + D2 \tan \theta_3 \left[ 1 + \left( 1 + \frac{\theta_3}{\sin \theta_3 \cos \theta_3} \right) \frac{1}{2B} \right] \quad (144)$$

MINIMIZE EXPRESSION FOR RANGE BY CONJUGATE DIRECTIONS.

The range is varied by incrementing the angle  $\theta_{rc}$  by  $\text{delt} = \frac{\pi}{100}$  radian:

$$\text{AUX} = \theta_{rc} + \frac{\pi}{100} \quad (145)$$

It is assumed the incremented angle AUX is between  $\pi/2$  and the angle of total internal reflection.

IF  $(\text{AUX} \geq \frac{\pi}{2})$  GO TO 500.

IF  $(\text{AUX} \leq \text{TIR})$  GO TO 500.

The angle  $\theta_3$  is recomputed in terms of the incremented value of  $\theta_{rc}$  and a new range RAUX is computed by the same formula that gives R above. If the new range, RAUX, is less than the old one, R, the procedure is repeated until the new one, RAUX, becomes greater than the old one, R. When this occurs, the increment  $\text{delt}$  is change to  $-\frac{\text{delt}}{3}$  and the process repeats until convergence occurs, i.e. IF  $|\text{delt}| \leq 1 \times 10^{-4}$ . The idea of this iterative process can be illustrated by figure 10 shown here adapted from figure 8.b. of Spofford et al. (1982).

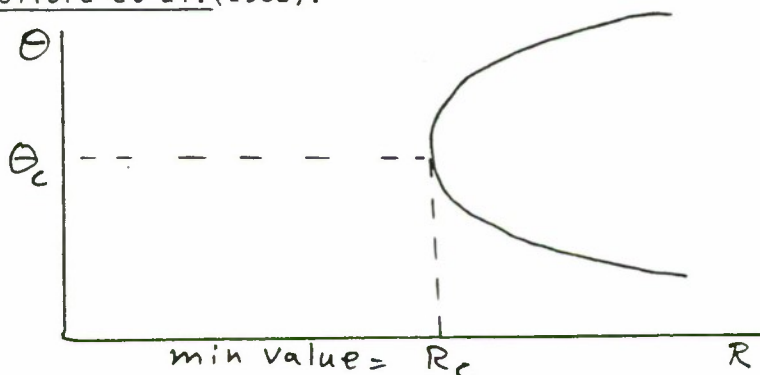


Figure 10. Illustration of minimum value of range at the caustic angle.

BOTTOM ANGLE OF REFRACTED RAY AT CRITICAL ANGLE

FIGURE 11. ILLUSTRATION OF CAUSTIC RAY PATH AND ANGLES

The speed at the greatest depth in the sediment reached by the basement grazing ray found from the formula for the sound speed profile as a function of the depth assumed by the model is

$$CB = \sqrt{2g_0(1+B)C_3BZ + C_3^2(1+B)^2} - BC_3 \quad (147)$$

$\text{THIB} = \cos^{-1} \frac{C_1}{C_B} = \theta_{1B}$ , the grazing angle in the water for the basement grazing (148)  
 ray is found from Snell's law.

RETURN

END (of SUBROUTINE TOTCRIT)

We now continue with SUBROUTINE CANGLE

COMPUTE CRITICAL RAY DEPTH      CRD

From Snell's law, the speed at the greatest depth of the caustic ray is

$$CAUX = \frac{C_1}{\cos \theta_{rc}} \quad (149)$$

We previously found the equation for BZ the sediment thickness as a function of CZ the sound speed at the corresponding depth. Now let's use the same equation with BZ = CRD, CZ = CAUX and  $C_2 = C_3$  the sound speed at the top of the sediment so  $CRD = \frac{1}{2g_0(1+B)C_3} [(CZ + BC_3)^2 - C_3^2(1+B)^2]$  (150) as given in SUBROUTINE CANGLE and illustrated in figure 11.

CALCULATE VELOCITY, VELOCITY GRADIENT, AND ATTENUATION CONSTANT AT DEPTH OF 500 METERS.

Setting depth in sediment Z = 500 meters and using the formula for the assumed sound speed profile we find the speed in the sediment at depth 500 meters to be

$$BSPD = [2g_0(1+B)(C_3)(500) + C_3^2(1+B)^2]^{\frac{1}{2}} - BC_3 \quad (151)$$

where  $C_3$  is sound speed at the top of the sediment. The sound speed gradient at 500 meters depth in the sediment is, from the assumed sound speed gradient equation,

$$BGRAD = \frac{g_0(1+B)C_3}{BSPD + BC_3} \quad (152)$$

The sound absorption coefficient is found to be

$$\begin{aligned} ALBOT = K &= K_0 + k_0' Z \\ &= \alpha_0 + \gamma(500) \end{aligned} \quad (153)$$

COMPUTE TWO WAY TRAVEL TIME IN SECONDS

$$TWTT = 2T$$

$$SPRAT = C_2/C_1$$

COMPUTE BASEMENT CRITICAL ANGLES TH1B, TH3B

Sound speed in the sediment at the basement level is found from the sound speed profile equation

$$CB = \sqrt{2g_0(1+B)C_3(BZ) + (1+B)^2 C_3^2} - BC_3 \quad (154)$$

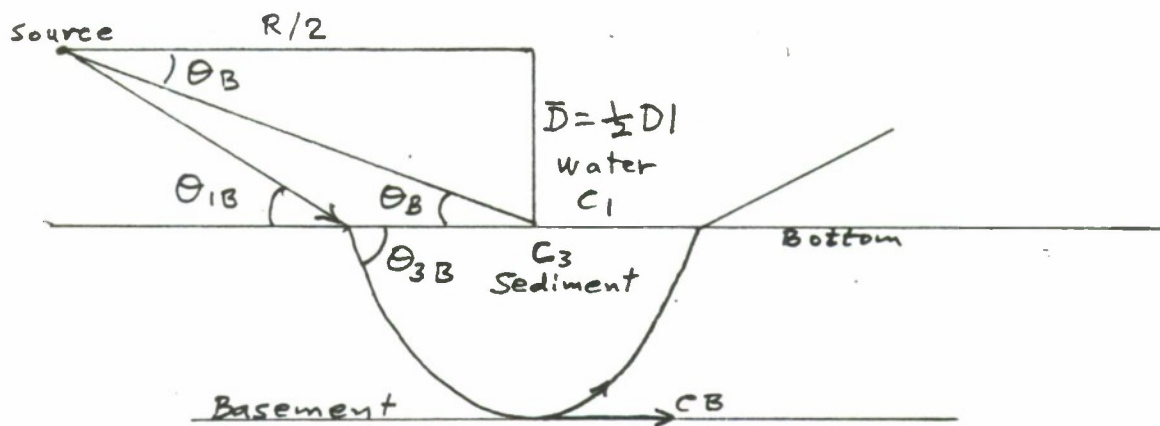


Figure 12. Illustration of basement grazing ray path.

For a refracted ray with its vertex at the basement as shown in figure 12,

Snell's law gives

$$\cos \theta_{1B} = \frac{c_1}{c_B} \quad (155)$$

$$\theta_{1B} = \cos^{-1} \frac{c_1}{c_B} \quad (156)$$

which is the largest bottom grazing angle for a ray which is refracted above the basement, and

$$\theta_{3B} = \cos^{-1} \frac{c_3}{c_B} \quad (157)$$

In terms of these angles the range equation becomes

$$R = \frac{D1}{\tan \theta_{1B}} + \frac{2BC_3 \tan \theta_{3B}}{g_0(1+B)} \left[ 1 + \frac{1}{2B} \left( 1 + \frac{\theta_{3B}}{\sin \theta_{3B} \cos \theta_{3B}} \right) \right] \quad (158)$$

as in SUBROUTINE CANGLE.

COMPUTE SMALLEST APPARENT ANGLE FOR BASEMENT REFLECTION.

From the value of R found last

$$\theta_B = \tan^{-1} \frac{D1}{R} \quad (159)$$

as shown in figure 12. If the angle is larger than this, there will be a reflection from the basement.

CHANGE RADIANs TO DEGREES

$$\theta_B = \theta_B \times 180/\pi$$

$A = TIR \times 180/\pi$  = angle of total internal reflection

$A_1 = \theta_c \times 180/\pi$  = apparent caustic angle in the water at the bottom

$A_2 = \theta_{rc} \times 180/\pi$  = caustic ray grazing angle in the water at the bottom

$A_3 = \theta_{1B} \times 180/\pi$  = smallest bottom grazing angle in the water for reflection from the basement.



PRINT OUT CRITICAL ANGLES

Format "CRITICAL ANGLES" - - -

RETURN

END (of subroutine CANGLE). We go back to main program and

PRINT GEO-PARAMETERS in Format "GEO-PARAMETERS" - - -

CALL ROUTINES FOR FREQUENCY--INDEPENDENT INTERMEDIATE VARIABLE

The subroutines REFL, REFR, and BASE are used to compute quantities needed in the bottom loss subroutine, LOSS. CALL REFL

**SUBROUTINE REFL**

NSAP = smallest angle to reach surface due to sound profile.

COMPUTE NSAP

NSAP = 1 is defined.

IF ( $C_1 \geq C_s$ ) go to 100.

For a ray path as shown in figure 13,

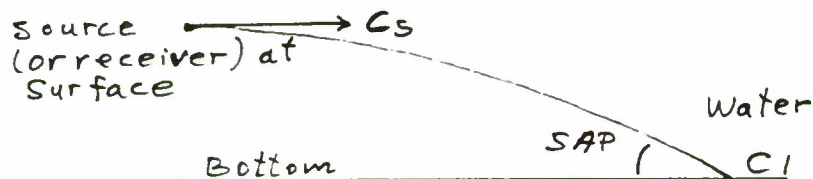


Figure 13. Illustration of ray path with limiting smallest angle SAP.

a ray may be horizontal at the source and have a bottom grazing angle SAP

where Snell's law gives

$$\frac{C_s}{1} = \frac{C_1}{\cos SAP} \quad (160)$$

$SAP = \cos^{-1} \frac{C_1}{C_s}$  If  $C_1 \geq C_s$  this calculation will be skipped--the angle '(161)' is unrealistic.

NSAP = SAP + 1 is redefined.

SAP is printed in format "SMALLEST ANGLE TO REACH SURFACE." - - -

COMPUTE REFLECTION COEFFICIENTS FOR ANGLES GREATER THAN TIR, SAP

NTIR = TIR + 1 angle in degrees.

N = MAX0 (NTIR, NSAP) says pick the largest of the angles expressed as integers in degrees.

$Z = \rho_1 C_1$   
 $Z_2 = \rho_2 C_2$   
 $Z_3 = \rho_3 C_3$

These are constants to be used in computing impedances needed to find reflection coefficients.

DELTA =  $\pi/180$  is used to convert angle in degrees to radians and as an increment in angle for a one degree change.

TH =  $(NSAP-1)\pi/180 = \theta$  is angle equal to SAP.

$FAC\ 2 = C_2/C_1$   
 $FAC\ 3 = C_3/C_1$   
 $FAC\ S = C_s/C_1$

These are speed ratios.

AR =  $2ZR/CS$  = twice travel time from receiver to surface.

AS =  $2ZS/CS$  = twice travel time from source to surface.

D1 =  $2\bar{D}$  = twice average distance from source and receiver to bottom.

DO 200 I = NSAP, 90 and IF (I<N) GO TO 200 insure the following calculations are performed for angles varying by steps of 1 degree:

For angles greater than the larger of TIR, SAP Surface Scattering Travel Time Differences, SIN2, Reflection Coefficients, Travel Time, and Geometric Intensity are computed. If  $SAP < TIR$ , for each step from SAP to TIR Surface Scattering Travel Time Differences only are computed because total internal reflection occurs in this range of angles, so the reflection coefficient is unity and special calculations of the other quantities are not applicable.

For each step from TIR to 90 all quantities are calculated.

#### SURFACE SCATTERING TRAVEL TIME DIFFERENCES

The sine of the angle made by the ray at the source is found from Snell's law

$$\cos \theta_s = \frac{C_s}{C_1} \cos \theta_1 \quad \text{and the identity} \quad (162)$$

$$\sin^2 \theta_s = 1 - \cos^2 \theta_s \quad \text{where } \theta_1 \text{ is the bottom grazing angle.} \quad (163)$$

$$S = \sin \theta_s = \sqrt{1 - \left(\frac{C_s}{C_1}\right)^2 \cos^2 \theta_1}$$

Travel time difference can be found as illustrated by the following figure.

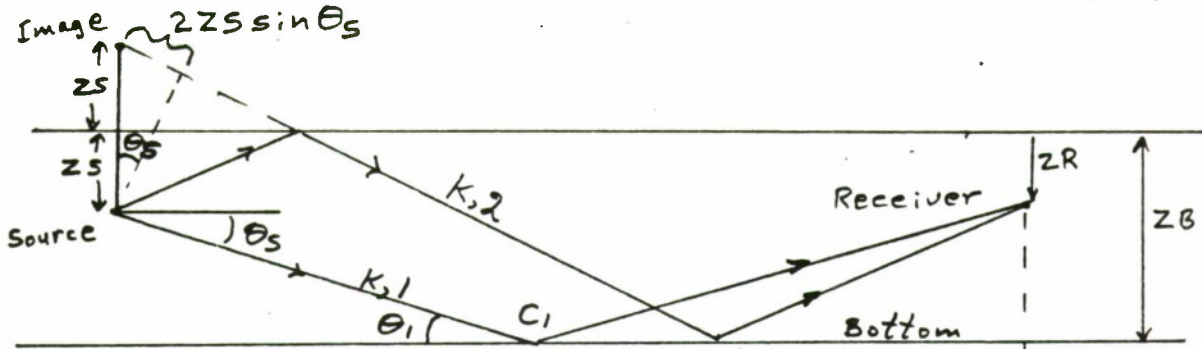


Figure 14. Bottom reflected only and surface scattered path difference.

Two different paths are designated K,1 and K,2. The assumption is made that the bottom grazing angle is approximately the same for the two paths. Then the surface reflected path, K,2, will be longer than the path K,1 by approximately  $2ZS \sin \theta_s$  and the travel time difference is

$$2 \left( \frac{ZS}{CS} \right) \sin \theta_s \quad \text{which is} \quad (164)$$

$$RDTS(I) = (AS)(S) = 2 (ZS/CS) \sqrt{1 - \left( \frac{CS}{C_1} \right)^2 \cos^2 \theta_1} \quad (165)$$

Interchanging source and receiver in Figure 14 yields

$$RDTR(I) = 2 (ZR/CS) \sqrt{1 - \left( \frac{CS}{C_1} \right)^2 \cos^2 \theta_1} \quad (166)$$

$RSIN2(I) = \sin \theta_2$  the grazing angle in the high speed layer by a procedure similar to the one which yields S above.

#### REFLECTION COEFFICIENTS

$$A_1 = Z_1 / \sin \theta_1 = \frac{P_1 C_1}{\sin \theta_1} \quad (167)$$

$$A_2 = Z_2 / RSIN2(I) = \frac{P_2 C_2}{\sin \theta_2}$$

$$A_3 = Z_3 / \sin \theta_3 = \frac{P_3 C_3}{\sin \theta_3}$$

These are the acoustic impedances (168) of the water, layer, and sediment. (169)

$\left. \begin{array}{l} RV32(I) \\ RV21(I) \end{array} \right\}$  These are reflection coefficients for the boundaries designated.

$$RGI(I) = \frac{\cos \theta_1}{R} = \frac{1}{R/\cos \theta_1} = \frac{1}{\text{slant range}} \quad (170)$$

is the factor for spherical spreading which represents decrease of amplitude with range.

RETURN

END (of SUBROUTINE REFL) (Go back to main program.)

CALL REFR

SUBROUTINE REFR

NTIR = TIR+1            gives angle in degrees.

NTHC = THC+1            Caustic angle + 1 degree.

N = NTHC - NTIR        integer giving difference between the caustic angle and angle of total internal reflection in degrees.

DEL =  $\pi/180$  is an increment of 1 degree expressed in radians.

TH is the caustic grazing angle expressed in radians =  $\theta_{rc}$ .

$\left. \begin{matrix} Z_1 \\ Z_2 \\ Z_3 \end{matrix} \right\}$  factors used to compute reflection and transmission coefficients.

$\left. \begin{matrix} FAC2 \\ FAC3 \\ FACS \end{matrix} \right\}$  sound speed ratios

SEST =  $\theta_{rc}$   
BEST =  $\theta_{rc}$  } Starting estimates of small and big angles.

D1 through D14 are factors to be used in computation of geometric amplitude and other quantities to follow. They are expressed in terms of the same quantities used before, e.g. in SUBROUTINE GCOMP and GEOPHYS.

DO 10 I=1,90 sets the array for transmission coefficients = 0.

DO 100 I=1,N and

J = NTHC-1 insures computation is done for each integer angle between caustic angle and angle of total internal reflection.



$R = D1/\tan TH$  gives the range not including that portion required for refraction in the bottom.

CALL REFRANG

#### SUBROUTINE REFRANG

IF  $TH > TIR$  go to 100. Otherwise print

"SPECULAR ANGLE OF REFRACTED RAY LESS THAN TIR"

and stop computation.

$$D1 = 2\bar{D}$$

$$PI2 = \pi/2$$

$$D2 = 2C_3B/g_0(1+B)$$

$$D3 = \frac{1}{2B}$$

$$FAC3 = C_3/C_1$$

$$R = D1/\tan TH$$

$$T3 = \cos^{-1}\left(\frac{C_3}{C_1}\right) \cos(SEST) = \theta_3 \quad \text{gives (by Snell's law) angle in sediment for (171)}$$

bottom grazing angle SEST.

$$VAL = \left[ \frac{2\bar{D}}{\tan SEST} + \frac{2C_3B}{g_0(1+B)} \tan \theta_3 \left( 1 + \frac{1}{2B} \left( 1 + \frac{\theta_3}{\sin \theta_3 \cos \theta_3} \right) \right) \right] - R \quad (172)$$

$VAL = R' - R$  as shown in Figure 15, the difference between a computed range from estimated angles and the actual range.

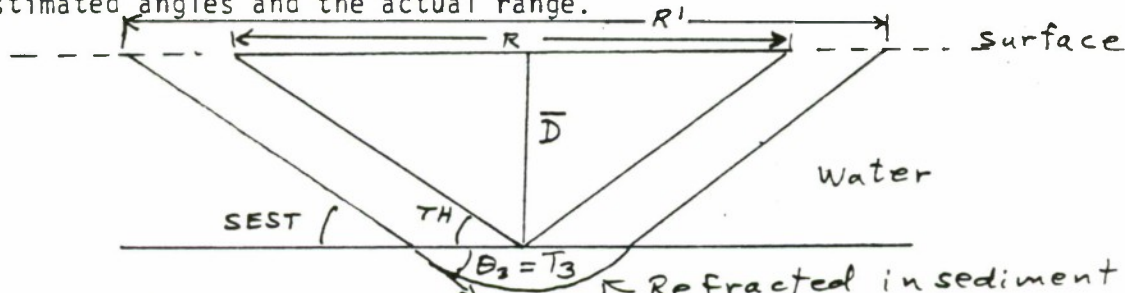


Figure 15. The range as found from estimated angles and the actual range.

$$DEL = \frac{SEST - TIR}{10.0001} \text{ is angle increment.}$$

The angles SA and BA correspond to rays a and b for range R2 shown in Figure 2.

#### COMPUTE SA

DO and IF statements start an iterative procedure which varies SEST and  $\theta_3$  by + or - increments until  $|DEL| < 1 \times 10^{-6}$  while insuring  $TIR \leq SA \leq \theta_{rc}$ . When convergence is completed, the error VAL between  $R'$  and R will be very small and the smallest bottom grazing angle SA for which a ray refracted in the sediment can travel from source to receiver is found. If convergence does not occur after 500 iterations, the statement is printed "SMALL BOTTOM REFRACTION ANGLE DOES NOT CONVERGE," and the procedure stops.

SA3=T3 gives the angle of the ray at the top of the sediment corresponding to the bottom grazing angle SA.

#### BA INITIALIZATION

$T3 = \theta_3 = \cos^{-1} \frac{C_3}{C_1} \cos \text{BEST}$  is the angle at the top of the sediment for bottom grazing angle BEST (with initial value  $\theta_{rc}$ ).

VAL has the same significance as in COMPUTE SA with SEST replaced by BEST.

#### COMPUTE BA

DO and IF statements generate an iterative procedure which varies BEST and  $\theta_3$  by + or - increments as needed until  $|DEL| < 1 \times 10^{-6}$  while insuring  $SA \leq BA \leq \theta_{rc}$ .

The procedure is similar to the one for COMPUTE SA. Upon convergence the biggest bottom grazing angle BA for which a ray refracted in the sediment can travel from source to receiver is found. If convergence does not occur after 500 iterations, the statement is printed "LARGE BOTTOM REFRACTION ANGLE DOES NOT CONVERGE," and computation stops.

BA3=T3= $\theta_3$  gives the angle of the ray at the top of the sediment corresponding to the bottom grazing angle BA.

#### RETURN

END (of subroutine REFRANG). Now we go back to SUBROUTINE REFR.

IF (BA > THIB) go to 998. THIB =  $\cos^{-1} \frac{C_1}{C_B}$  so for BA > THIB the ray hits the basement. (173)

Otherwise, compute the sines of grazing angles BA and corresponding angles for the same ray in the layer and sediment.

$$BC1 = \cos BA \quad (174)$$

$$BS1 = \sin BA = \sqrt{1 - \cos^2 BA} \quad (175)$$

$$BC2 = \frac{C_2}{C_1} \cos BA \text{ (Snell's law)} \quad (176)$$

$$BS2 = \sqrt{1 - (BC2)^2} = \sin \theta_2 \text{ (in layer)} \quad (177)$$

$$BC3 = \frac{C_3}{C_1} BC1 = \frac{C_3}{C_1} \cos BA = \cos \theta_3 \quad (178)$$

$$BS3 = \sin \theta_3 \text{ (in sediment)} \quad (179)$$

BIG ANGLE REFLECTION COEFFICIENT

$$A_1 = Z_1 / \sin BA \quad (180)$$

$$A_2 = Z_2 / \sin \theta_2 \quad \left. \begin{array}{l} A_3 = Z_3 / \sin \theta_3 \end{array} \right\} \text{Acoustic impedances used to compute reflection coefficients.} \quad (181)$$

$$A_3 = Z_3 / \sin \theta_3 \quad (182)$$

$$BV32(J) = (A_3 - A_2) / (A_3 + A_2) \quad \left. \begin{array}{l} BV21(J) = (A_2 - A_1) / (A_2 + A_1) \end{array} \right\} \text{Big angle reflection coefficients for boundaries} \quad (183)$$

$$\text{designated by the subscripts.} \quad (184)$$

Big angle transmission coefficient factor (two-way)

$$BTRF = 16 A_1 A_3 \left( \frac{A_2}{(A_3 + A_2)(A_2 + A_1)} \right)^2 \quad (185)$$

similar to the one in Subroutine GEOPHYS.

$$BSIN2(J) = \sin \theta_2 \text{ (in layer)} \quad (186)$$

GEOMETRIC AMPLITUDE

The geometric spreading loss factor, equation (38) of Spofford et al. (1982) is

$$\frac{I}{I_0} = \frac{1}{R \tan \theta_b \left| \frac{dR}{d\theta} \right|_{\theta=\theta_b}} \quad (187)$$

We are dealing with the amplitude or pressure ratio so let

$$BGI(J) = \sqrt{\frac{1}{R \tan BA \left| \frac{dR}{dBA} \right|}} = P/P_0 \quad (188)$$

We need the derivative  $\frac{dR}{d\theta_1}$ . Taking the range formula from Subroutine GCOMP or

equations (16) and (21) of Spofford et al. (1982) with appropriate substitutions of angles

$$\text{gives } R = \frac{D1}{\tan \theta_1} + \frac{F_1}{g_0} F_2 \tan \theta_3 \quad (189)$$

$$\text{where } F_1 = \frac{2BC_3}{(1+B)} \quad \text{and } F_2 = \left[ 1 + \frac{1}{2B} \left( 1 + \frac{\theta_3}{\sin \theta_3 \cos \theta_3} \right) \right] \quad (190)$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2 \theta_1} + \frac{F_1}{g_0} \left[ \frac{dF_2}{d\theta_1} \tan \theta_3 + F_2 \sec^2 \theta_3 \frac{d\theta_3}{d\theta_1} \right] \quad (191)$$

$$\frac{dF_2}{d\theta_1} = \frac{dF_2}{d\theta_3} \frac{d\theta_3}{d\theta_1} \quad (192)$$

From Snell's law  $\cos \theta_1 = \frac{C_1}{C_3} \cos \theta_3$  and differentiating gives (193)

$$-\sin \theta_1 = -\frac{C_1}{C_3} \sin \theta_3 \frac{d\theta_3}{d\theta_1} \quad (194)$$

$$\frac{d\theta_3}{d\theta_1} = \frac{C_3}{C_1} \frac{\sin \theta_1}{\sin \theta_3} \quad (195)$$

$$\frac{dF_2}{d\theta_1} = \frac{1}{2B \sin \theta_3 \cos \theta_3} \left[ 1 + \theta_3 \left( \frac{\sin^2 \theta_3 - \cos^2 \theta_3}{\sin \theta_3 \cos \theta_3} \right) \right] \left( \frac{C_3}{C_1} \right) \frac{\sin \theta_1}{\sin \theta_3} \quad (196)$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2 \theta_1} + \frac{F_1}{g_0} \left\{ \frac{C_3 \sin \theta_1}{2BC_1 \sin \theta_3 \cos^2 \theta_3} \left[ 1 + \theta_3 \left( \frac{\sin^2 \theta_3 - \cos^2 \theta_3}{\sin \theta_3 \cos \theta_3} \right) \right] \right\} \quad (197)$$

$$+ F_2 \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3 \cos^2 \theta_3} \left\{ \right.$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2 \theta_1} + \frac{F_1}{g_0} \left( \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3 \cos^2 \theta_3} \right) \left\{ \frac{1}{2B} \left[ 1 + \theta_3 \left( \frac{\sin^2 \theta_3 - \cos^2 \theta_3}{\sin \theta_3 \cos \theta_3} \right) \right] \right. \quad (198)$$

$$\left. + F_2 \right\}$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2 \theta_1} + \frac{F_1}{g_0} \left( \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3 \cos^2 \theta_3} \right) \quad (199)$$

$$\times \left[ \frac{1}{2B} - \frac{1}{2B} \frac{\theta_3 (2 \cos^2 \theta_3 - 1)}{\sin \theta_3 \cos \theta_3} + \frac{2B}{2B} + \frac{1}{2B} + \frac{\theta_3}{2B \sin \theta_3 \cos \theta_3} \right]$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2 \theta_1} + \frac{F_1}{g_0 (2B)} \left( \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3 \cos^2 \theta_3} \right) \quad (200)$$

$$\times \left[ 1 - \frac{2 \theta_3 \cos^2 \theta_3}{\sin \theta_3 \cos \theta_3} + \frac{\theta_3}{\sin \theta_3 \cos \theta_3} + (2B+1) + \frac{\theta_3}{\sin \theta_3 \cos \theta_3} \right]$$



$$\frac{dR}{d\theta_1} = -\frac{D_1}{\sin^2 \theta_1} + \frac{F_1}{Bg_0} \left( \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3 \cos^2 \theta_3} \right) \quad (201)$$

$$\times \left[ (1+B) + \frac{\theta_3}{\sin \theta_3 \cos \theta_3} (1 - \cos^2 \theta_3) \right],$$

$$\frac{dR}{d\theta_1} = -\frac{D_1}{\sin^2 \theta_1} + \frac{F_1}{Bg_0} \left( \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3 \cos^2 \theta_3} \right) [1+B+\theta_3 \tan \theta_3], \quad (202)$$

$$\frac{dR}{d\theta_1} = -\frac{D_1}{\sin^2 \theta_1} + \frac{(1+B)}{B} \left( \frac{F_1}{g_0} \right) \left( \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3 \cos^2 \theta_3} \right) \left( 1 + \frac{\theta_3 \tan \theta_3}{1+B} \right), \quad (203)$$

Substituting the expression for  $F_1$  gives

$$\frac{dR}{d\theta_1} = -\frac{D_1}{\sin^2 \theta_1} + \left( \frac{1+B}{B} \right) \left( \frac{2BC_3}{1+B} \right) \left( \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3 \cos^2 \theta_3} \right) \left( 1 + \frac{\theta_3 \tan \theta_3}{1+B} \right) \quad (204)$$

and substituting in the factors

$$D_2 = \frac{2C_3^2}{C_1 g_0}, \quad D_7 = (1+B), \quad \theta_1 = BA, \quad \sin \theta_1 = BS_1, \quad (205)$$

$$\sin \theta_3 = BS_3, \quad \cos \theta_3 = BC_3, \quad \theta_3 = BA_3, \quad \tan \theta_3 = \tan BA_3 \quad (206)$$

gives the equation

$$DRDT = -\frac{D_1}{\sin^2 BA} + \frac{D_2 \sin BA}{\sin BA_3 \cos^2 BA_3} \left( 1 + \frac{BA_3 \tan BA_3}{D_7} \right) \quad (207)$$

as in the SUBROUTINE REFR.

This is the derivative of the range with respect to the bottom grazing angle evaluated at the Big Angle in the water. With this derivative DRDT we compute BGI(J) as in the subroutine for the Big Angle.

#### ARC LENGTH

Our model assumes that loss mechanisms in sediments behave linearly, e.g. loss

$L = K \cdot S \cdot f$  by equation (13) of Spofford et al. (1982), or in terms of symbols used in our program  $DL = \alpha_0 S F_K$ , so in the program it is assumed the frequency averaged or effective value of the sound path, ARC LENGTH, in the sediment is given by

$S = \frac{DL}{\alpha_0 F_K}$  where DL is dissipation loss in the sediment given by (208) equation (23) of Spofford et al. (1982), or as shown in Subroutine GEOPHYS,  $\alpha_0$

is the average value of attenuation constant for this path length, and  $F_K$  denotes the center frequency of a one-octave measured bandwidth. Thus, let

$BLS = \frac{DL}{\alpha_0 F_K}$  and in terms of the equation for DL with lower limit  $\theta^1=0$ , upper (209) limit  $\theta_0=\theta_3$  and the factors from this subroutine, D8 through D14, we get

$$BLS = \frac{2C_3}{\alpha_0 \gamma_0 (1+B) \cos \theta_3} \left[ -\frac{\gamma C_3^2 (\sin \theta_3)^3}{6\sigma (\cos \theta_3)} - \frac{(B\gamma C_3^2 + 2\gamma \nu C_3) \sin \theta_3}{4\sigma \cos \theta_3} \right. \\ + \frac{\gamma C_3^2 \sin \theta_3}{2\sigma \cos^2 \theta_3} + \frac{(\gamma(\nu^2 - \mu) + 2\alpha_0 \sigma + 2B\nu C_3 \sigma) \sin \theta_3}{4\sigma \cos^2 \theta_3} \\ \left. + \frac{(B\gamma C_3^2 + 2\gamma \nu C_3) \theta_3}{4\sigma \cos^2 \theta_3} + \left( \frac{2\sigma \cos \theta_3}{B\gamma(\nu^2 - \mu) + \alpha_0 B} + \alpha_0 B \right) \theta_3 \right] \quad (210)$$

as in the subroutine statement for the ARC LENGTH

#### TRAVEL TIME

We need the total travel time of a path with bottom grazing angle BA (Big Angle). We first find the travel time in the sediment. By definition  $C(Z) = \frac{dS}{dt}$  where S is an element of path length. The vertical component of dS is

$dz = \sin \theta dS$  so  $dS = dz/\sin \theta$ , and, noting that  $\theta = \theta(z)$ , we have

$$dt = \frac{dS}{c(z)} = \frac{dz}{c(z) \sin \theta(z)} \quad \text{from which} \quad (211)$$

$$T_s = 2 \int_0^{\bar{z}} \frac{dz}{c(z) \sin \theta(z)} \quad (212)$$

This is equation (19) of Spofford et al. (1982) where  $\bar{z}$  represents the turning point depth or basement depth for rays which reflect from the basement.

Snell's law gives  $C(z) = c_0 \frac{\cos \theta(z)}{\cos \theta_0}$  where  $c_0$  is the sound speed at the top (213)

of the sediment and  $\theta_0$  is the angle at the top of the sediment. Differentiate this with respect to  $z$ .

$$-\sin \theta \frac{d\theta}{dz} = \frac{\cos \theta_0}{c_0} \frac{dC(z)}{dz} = \frac{\cos \theta_0}{c_0} g(z) \quad (214)$$

$$\frac{1}{\sin \theta} = -\frac{c_0}{g(z) \cos \theta_0} \frac{d\theta}{dz} \quad (215)$$

$$T_S = 2 \int_0^{\tilde{z}} -\frac{c_0 \frac{d\theta}{dz} dz}{g(z) C(z) \cos \theta_0} \quad (216)$$

$$T_S = -\frac{2c_0}{\cos \theta_0} \int_{\theta_0}^{\theta'} \frac{d\theta}{g(z) C(z)} \quad (217)$$

$$T_S = -\frac{2c_0}{\cos \theta_0} \int_{\theta_0}^{\theta'} \frac{d\theta}{\frac{g_0(1+B)c_0}{C(z) + Bc_0} C(z)} \quad (218)$$

$$T_S = -\frac{2}{\cos \theta_0} \int_{\theta_0}^{\theta'} \frac{(C(z) + Bc_0) d\theta}{g_0(1+B)C(z)} \quad (219)$$

$$T_S = -\frac{2}{g_0(1+B)\cos \theta_0} \int_{\theta_0}^{\theta'} \left(1 + \frac{Bc_0}{C(z)}\right) d\theta \quad (220)$$

$$T_S = -\frac{2}{g_0(1+B)} \int_{\theta_0}^{\theta'} \left(\frac{1}{\cos \theta_0} + \frac{B}{\cos \theta}\right) d\theta \quad (221)$$

$$T_S = -\frac{2}{g_0(1+B)} \left[ \frac{\theta}{\cos \theta_0} + B \ln(\sec \theta + \tan \theta) \right]_{\theta_0}^{\theta'} \quad (222)$$

Using a trig identity and interchanging the limits gives

$$T_S = \frac{2}{g_0(1+B)} \left[ \frac{\theta}{\cos \theta_0} + B \ln\left(\frac{\cos \theta}{1 - \sin \theta}\right) \right]_{\theta=\theta_0}^{\theta=\theta'} \quad (223)$$

This is equation (22) of Spofford et al. (1982). The time for travel in the water is the slant range divided by the sound speed in the water, i.e.  $D1/C1 \sin BA$ . Adding this to  $T_s$  where we substitute  $\theta' = 0$  for a path refracted in the sediment,  $\theta_0 = BA$ , and  $\sin BA = BS1$  yields

$$T = \frac{D1}{C1 BS1} + \frac{2}{g_0(1+B)} \left[ \frac{BA3}{\cos BA3} + B \ln \left( \frac{\cos BA3}{1 - \sin BA3} \right) \right] \quad (224)$$

Now  $\frac{\cos \theta}{1 - \sin \theta} = \left( \frac{1 + \sin \theta}{1 - \sin \theta} \right)^{1/2}$  so

$$T = \frac{D1}{C1 BS1} + \frac{2B}{g_0(1+B)} \left[ \frac{BA3}{B \cos BA3} + \frac{1}{2} \ln \left( \frac{1 + BS3}{1 - BS3} \right) \right]$$

$$T = \frac{D1}{C1 BS1} + \frac{B}{g_0(1+B)} \left[ \frac{2 BA3}{B(BC3)} + \ln \left( \frac{1 + BS3}{1 - BS3} \right) \right] = BT(J) \quad (225)$$

$$BT(J) = \frac{D5}{BS1} + D4 \left[ \ln \left( \frac{1 + BS3}{1 - BS3} \right) + \frac{2}{B} \left( \frac{BA3}{BC3} \right) \right] \quad (226)$$

which is the expression for the travel time in Subroutine REFR.

$$\text{DELTA T SOURCE RECEIVER (for Big Angle)} \quad (227)$$

$$BSS = \sqrt{1 - \left( \frac{CS}{C1} BC1 \right)^2} = \sqrt{1 - \cos^2 \theta_s} \quad \text{Snell's law with}$$

$$BC1 = \cos BA \text{ yields } \frac{CS}{C1} \cos BA = \cos \theta_s \text{ so} \quad (228)$$

$$BSS = \sin \theta_s \text{ where } \theta_s \text{ is ray angle at source (or receiver)} \quad (229)$$

$$BDTR(J) = D6(ZR) \sin \theta_s = 2 \left( \frac{ZR}{CS} \right) \sin \theta_s \text{ is the travel time difference for the } (230)$$

Big Angle path from source to bottom to surface to receiver.

$$\text{Similarly } BDTs(J) = 2 \left( \frac{Zs}{CS} \right) \sin \theta_s \text{ is the travel time difference for the Big } (231)$$

Angle path from source to surface to bottom to receiver.

We want to deal with rays not hitting the basement - refracted in sediment only, so the statement IF  $SA > \text{THIB} (= \cos^{-1} \frac{C1}{CB})$  go to 999 stops computation. Sound (232)

speed in sediment at basement level is CB and THIB is the bottom grazing angle of the refracted ray which reaches the bottom of sediment at basement level.

$$AUX = FACS * SC1 \quad (233)$$

$$= \frac{CS}{C1} \cos SA = \cos \theta_s \text{ where } \theta_s \text{ is angle at source (or receiver) for a ray with bottom grazing angle SA.} \quad (234)$$



IF RAY DOES NOT REACH SURFACE NOT COMPUTED

IF  $AUX > 1$  go to 999 stops computation if  $\cos \theta_s > 1$  which is not physically realistic.

DELTA T SOURCE RECEIVER (for Small Angle)

$$SSS = \sqrt{1 - (AUX)^2} = \sin \theta_s \text{ for bottom grazing angle SA.} \quad (235)$$

$$\left. \begin{aligned} SDTR(J) &= 2 \left( \frac{ZR}{CS} \right) \sin \theta_s \\ SDTS(J) &= 2 \left( \frac{ZS}{CS} \right) \sin \theta_s \end{aligned} \right\} \begin{array}{l} \text{Travel time difference for indirect path for (236)} \\ \text{surface reflections at receiver and source. (237)} \end{array}$$

Use of Snell's law and trig identity is made to define the following:

$$SS1 = \sqrt{1 - (SC1)^2} = \sin SA \quad (238)$$

$$SC2 = \frac{C_2}{C_1} \cos SA = \cos \theta_2 \text{ where } \theta_2 \text{ is the angle in the layer for ray with (239)}$$

bottom grazing angle SA,

$$SS2 = \sqrt{1 - (SC2)^2} = \sin \theta_2, \quad (240)$$

$$SC3 = \frac{C_2}{C_1} (SC1) = \frac{C_3}{C_1} \cos SA = \cos \theta_3 \text{ where } \theta_3 \text{ is angle at top of sediment for bottom (241)}$$

grazing angle SA,

$$SS3 = \sqrt{1 - (SC3)^2} = \sqrt{1 - \cos^2 \theta_3} = \sin \theta_3 \quad (242)$$

SMALL ANGLE REFLECTION COEFFICIENT

$$\left. \begin{aligned} A_1 &= Z_1 / \sin SA \\ A_2 &= Z_2 / \sin \theta_2 \\ A_3 &= Z_3 / \sin \theta_3 \end{aligned} \right\} \begin{array}{l} \text{Impedances corresponding to Small (243)} \\ \text{Angle ray.} \end{array}$$

$$\left. \begin{aligned} SV32(J) &= (A_3 - A_2) / (A_3 + A_2) \\ SV21(J) &= (A_2 - A_1) / (A_2 + A_1) \end{aligned} \right\} \begin{array}{l} \text{Reflection coefficients for boundaries} \\ \text{designated by subscripts. (244)} \end{array}$$

$$STRF(J) = 16 A_1 A_3 \left( \frac{A_2}{(A_3 + A_2)(A_2 + A_1)} \right)^2 \quad \begin{array}{l} \text{Two-way travel layer transmission} \\ \text{coefficient factor. (245)} \end{array}$$

$$SSIN2 = \sin \theta_2 \text{ for small angle ray.} \quad (246)$$

GEOMETRIC AMPLITUDE (for Small Angle)

DRDT - same as DRDT for Big Angle case with BA, BA3 changed to SA, SA3 etc.

This is the derivative of the range with respect to the bottom grazing angle evaluated at SA.

$$SGI(J) = \sqrt{\frac{\cos SA}{R \sin SA \left| \frac{dR}{dSA} \right|}} = \frac{P}{P_0}$$

the pressure ratio (247)  
for the Small Angle path.

This is the geometric spreading loss factor.

#### ARC LENGTH

SLS(J) is the same as BLS(J) with angles changed to those appropriate to the Small Angle path.

#### TRAVEL TIME

ST(J) is the same as BT(J) with angles changed to those appropriate to the Small Angle case.

999 TH=TH-DEL increments the angle. The computations are made in steps of 1 degree for all applicable angles.

RETURN

END (of Subroutine REFR) (Go back to the main program.) CALL BASE

#### SUBROUTINE BASE

The statements NTIR, DEL, TH, N=90-MAXΘ(N,NTIR), and DO 10 I=1,90 cause calculations to be made in steps of 1 degree for angles from the angle of total internal reflection or the apparent bottom angle for a ray vertexing at the bottom of the sediment, whichever is larger, to 90°. This insures reflections at the basement are accounted for. The Z's and FAC's are the same as used before.

$$CB = \sqrt{2g_0(1+B)(C_3)BZ + C_3^2(1+B)^2} - BC_3 \quad (248)$$

gives the sound speed in the sediment at the basement level.

D1 through D14 are factors used later.

$$BSA = \pi/2 - 1 \times 10^{-8} \quad (\text{used in Subroutine BASANG}) \quad (249)$$

TH3 =  $\cos^{-1} \frac{C_3}{C_1} \cos \theta_{1B} = \theta_3$  is angle at top of sediment corresponding to bottom grazing angle  $\theta_{1B}$  for a ray which reaches the bottom of the sediment.

R is the range for a ray refracted in the sediment with vertex at the basement.

This expression is found by substituting  $\theta_0 = \theta_3$ ,  $\theta' = 0$  into the equation for Rs giving

$$\begin{aligned}
 R_s &= \frac{C_3}{g_0(1+B)\cos\theta_3} \left[ \frac{\theta_3}{\cos\theta_3} + \sin\theta_3(1+2B) \right] \\
 &= \frac{C_3}{g_0(1+B)\cos\theta_3} \left[ \frac{\theta_3}{\cos\theta_3} + \sin\theta_3 + 2B\sin\theta_3 \right] \\
 &= \frac{C_3}{g_0(1+B)\cos\theta_3} \left[ \theta_3 + \frac{2\sin\theta_3\cos\theta_3}{2} + 2B\sin\theta_3\cos\theta_3 \right] \\
 &= \frac{C_3}{g_0(1+B)\cos^2\theta_3} \left[ \theta_3 + \frac{\sin 2\theta_3}{2} + B\sin 2\theta_3 \right] \\
 &= \frac{2C_3}{g_0(1+B)\cos^2\theta_3} \left[ \frac{\theta_3}{2} + \sin 2\theta_3 \left( \frac{1}{2} + B \right) \left( \frac{1}{2} \right) \right] \quad (251)
 \end{aligned}$$

$$R = \frac{D1}{\tan\theta_{1B}} + \frac{D3}{\cos^2\theta_3} \left[ \frac{\theta_3}{2} + \left( 0.25 + \frac{B}{2} \right) \sin 2\theta_3 \right]. \quad (252)$$

$AUX = \tan^{-1} \frac{D1}{R}$  This is the apparent angle for a ray tangent at the bottom (253)

of the sediment as shown in Figure 16.

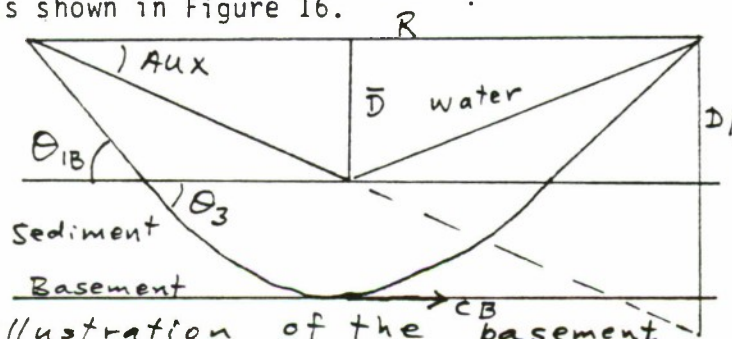


Figure 16. Illustration of the grazing ray path.

DO 10 I=1,90

BSS/N2(I)=0.0

BSV32(I) =0.0

BSV21(I) =0.0

BSGI(I) =0.0

Program modified by addition of these statements to insure completion of a run.

10 BSTRF(I)=0

clears registers

DO 100 I = 1,N  
J=90-I

orders computations for angles in the range mentioned.

TH=TH-DEL increments angles

CALL BASANG

SUBROUTINE BASANG

IF  $TH > TIR$  GO TO 100 allows computations to proceed for angles greater than TIR.  
Otherwise print "SPECULAR ANGLE OF BASEMENT RAY LESS THAN TIR" and computation stops. CB is same as in Subroutine BASE--sound speed at basement level of sediment. The next several factors are like ones used before.  
BEST = BSA is estimate of basement reflected ray angle in water.



$$AUX = \cos BSA$$

(254)

$$THB = \cos^{-1} \left( \frac{CB}{C_1} \right) \cos BSA = \theta_B \text{ angle of ray at basement.}$$

(255)

$$TH3 = \cos^{-1} \left( \frac{C_3}{C_1} \right) \cos BSA = \theta_3 \text{ angle of ray at top of sediment.}$$

(256)

Now find the range in terms of  $\theta_B$  and  $\theta_3$  as limits from previous equations for

R and Rs.

$$R_s = \frac{C_3}{g_0(1+B)\cos\theta_3} \left[ \frac{\theta_3}{\cos\theta_3} + \frac{\sin\theta_3 \cos\theta_3}{\cos\theta_3} + 2B \sin\theta_3 - \frac{\theta_B}{\cos\theta_3} - \frac{\sin\theta_B \cos\theta_B}{\cos\theta_3} - 2B \sin\theta_B \right], \text{ where} \quad (257)$$

$$\theta_0 = \theta_3 \text{ and } \theta' = \theta_B.$$

$$R_s = \frac{D_2}{\cos^2\theta_3} \left[ \frac{\theta_3 - \theta_B}{\cos\theta_3} + \frac{\sin\theta_3 \cos\theta_3 - \sin\theta_B \cos\theta_B}{2} + B \frac{C_3}{C_1} \cos BSA (\sin\theta_3 - \sin\theta_B) \right] \quad (258)$$

$$R_s = \frac{D_2}{\left( \frac{C_3}{C_1} \cos BSA \right)^2} \left[ \frac{\theta_3 - \theta_B}{2} + \frac{\sin 2\theta_3 - \sin 2\theta_B}{4} + B \left( \frac{C_3}{C_1} \right) \cos BSA (\sin\theta_3 - \sin\theta_B) \right]. \quad \text{This is} \quad (259)$$

the second term in VAL. From the formula for R we see

$$VAL = \frac{D_1}{\tan BEST} + \frac{D_2}{\left( \frac{C_3}{C_1} \cos BSA \right)^2} \left[ \frac{\theta_3 - \theta_B}{2} + \frac{\sin 2\theta_3 - \sin 2\theta_B}{4} + B \frac{C_3}{C_1} \cos BSA (\sin\theta_3 - \sin\theta_B) \right] - \frac{D_1}{\tan TH}, \quad (260)$$

where TH is the apparent bottom angle. This VAL is similar to the one used in SUBROUTINE REFRANG except basement reflection occurs. See Figure 15.

Now the IF and DO statements start iterations which adjust the angles to make

VAL approach zero until convergence is obtained when  $|DEL| < 1 \times 10^{-6}$  whereupon

BEST=BSA. If convergence does not occur, print "BASEMENT ANGLE DOES NOT CONVERGE."

and stop computation.

The basement reflected ray angle at the top of the sediment is

BSA3=TH3=  $\theta_3$  and BSA is the basement reflected ray angle in the water. We (261)  
use BSA and BSA3 in SUBROUTINE BASE.

RETURN

END (of subroutine BASANG) Go back to SUBROUTINE BASE.

IF (BSA3.EQ.0.0) GO TO 100-added to insure completion of run.

$$BC1 = \cos BSA \quad (262)$$

$$BS1 = \sin BSA \quad (263)$$

$$BC2 = \frac{C2}{C1} \cos BSA = \cos \theta_2, \theta_2 \text{ is in the layer.} \quad (264)$$

$$BS2 = \sin \theta_2 \text{ in layer} \quad (265)$$

$$BC3 = \frac{C3}{C1} \cos BSA = \cos \theta_3, \theta_3 \text{ is at top of sediment.} \quad (266)$$

$$BS3 = \sin \theta_3 \quad (267)$$

$$BCB = \frac{CB}{C1} \cos BSA = \cos \theta_B, \theta_B \text{ is basement grazing angle in the sediment.} \quad (268)$$

$$BSB = \sin \theta_B \quad (269)$$

DELTA T SOURCE RECEIVER

$$AUX = \frac{C_s}{C1} \cos BSA = \cos \theta_s \text{ where } \theta_s \text{ is angle at the source for the basement} \quad (270)$$

reflected ray.

IF RAY DOES NOT REACH SURFACE NOT COMPUTED.

IF AUX > 1 go to 999 stops computation if  $\cos \theta_s > 1$  which is not realistic in nature.

$$SS = \sqrt{1 - (AUX)^2} = \sqrt{1 - \cos^2 \theta_s} = \sin \theta_s \quad (271)$$

$$\left. \begin{aligned} BSDTR(J) &= 2 \left( \frac{ZR}{CS} \right) \sin \theta_s \\ BSDTS(J) &= 2 \left( \frac{ZS}{CS} \right) \sin \theta_s \end{aligned} \right\} \quad \begin{array}{l} \text{Travel time differences for receiver} \\ \text{and source respectively.} \end{array} \quad (272)$$

LAYER REFLECTION COEFFICIENTS

$$\left. \begin{aligned} A_1 &= Z_1 / \sin BSA \\ A_2 &= Z_2 / \sin \theta_2 \\ A_3 &= Z_3 / \sin \theta_3 \end{aligned} \right\} \quad \begin{array}{l} \text{Acoustic impedances, medium designated} \\ \text{by subscripts.} \end{array} \quad (273)$$

$$\left. \begin{aligned} \text{BSV32}(J) &= (A_3 - A_2) / (A_3 + A_2) \\ \text{BSV21}(J) &= (A_2 - A_1) / (A_2 + A_1) \end{aligned} \right\} \quad \begin{array}{l} \text{Reflection coefficients for} \\ \text{boundaries designated by subscripts.} \end{array} \quad (274)$$

$$\text{BSTRF}(J) = 16 A_1 A_3 \left( \frac{A_2}{(A_3 + A_2)(A_2 + A_1)} \right)^2 \quad (275)$$

This is a two-way layer transmission coefficient factor for basement reflected ray.

BSSIN2(J) =  $\sin \theta_2$ ,  $\theta_2$  is angle in layer.

(276)

# GEOMETRIC AMPLITUDE

BSAB =  $\cos^{-1}(\cos \theta_B) = \theta_B$  basement reflection angle in sediment at basement.

We now find the derivative of the range with respect to the bottom-grazing angle,  $\theta_1$ .

$$R = \frac{DI}{\tan \theta_1} + \frac{DA}{2 \cos^2 \theta_3} \left[ \theta_3 - \theta_B + \sin \theta_3 \cos \theta_3 - \sin \theta_B \cos \theta_B \right] \quad (277)$$

$$+ \frac{DB}{\cos^2 \theta_3} \left[ \sin \theta_3 \cos \theta_3 - \sin \theta_B \cos \theta_3 \right].$$

$$\begin{aligned} \frac{dR}{d\theta_1} = & \frac{-DI}{\sin^2 \theta_1} + \frac{DA(-2)(-\sin \theta_3)}{2 \cos^3 \theta_3} \left( \frac{d\theta_3}{d\theta_1} \right) \left[ \theta_3 - \theta_B + \sin \theta_3 \cos \theta_3 \right. \\ & \left. - \sin \theta_B \cos \theta_B \right] \\ & + \frac{DA}{2 \cos^2 \theta_3} \left[ \frac{d\theta_3}{d\theta_1} - \frac{d\theta_B}{d\theta_3} \frac{d\theta_3}{d\theta_1} + (\cos^2 \theta_3 - \sin^2 \theta_3) \frac{d\theta_3}{d\theta_1} \right. \\ & \left. - (\cos^2 \theta_B - \sin^2 \theta_B) \frac{d\theta_B}{d\theta_3} \frac{d\theta_3}{d\theta_1} \right] \\ & + \frac{DB(2) \sin \theta_3}{\cos^3 \theta_3} \left( \frac{d\theta_3}{d\theta_1} \right) \left[ \sin \theta_3 \cos \theta_3 - \sin \theta_B \cos \theta_3 \right] \\ & + \frac{DB}{\cos^2 \theta_3} \left[ (\cos^2 \theta_3 - \sin^2 \theta_3) \frac{d\theta_3}{d\theta_1} - \cos \theta_B \cos \theta_3 \frac{d\theta_B}{d\theta_3} \frac{d\theta_3}{d\theta_1} \right. \\ & \left. + \sin \theta_B \sin \theta_3 \frac{d\theta_3}{d\theta_1} \right]. \end{aligned}$$

Snell's law:  $\frac{\cos \theta_3}{C_3} = \frac{\cos \theta_1}{C_1}$ , Differentiating gives (278)

$$-\frac{\sin \theta_3}{C_3} \frac{d\theta_3}{d\theta_1} = -\frac{\sin \theta_1}{C_1},$$

$$\frac{d\theta_3}{d\theta_1} = \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3}. \quad \text{Similarly,}$$

$$\frac{d\theta_B}{d\theta_3} = \frac{C_B \sin \theta_3}{C_3 \sin \theta_B}, \text{ and substituting these gives}$$



$$\begin{aligned}
\frac{dR}{d\theta_1} = & -\frac{D_1}{\sin^2 \theta_1} + \frac{DA \sin \theta_3}{\cos^3 \theta_3} \left( \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3} \right) \left[ \theta_3 - \theta_B + \sin \theta_3 \cos \theta_3 \right. \\
& \left. - \sin \theta_B \cos \theta_B \right] \\
& + \frac{DA}{2 \cos^2 \theta_3} \left( \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3} \right) \left[ 1 - \frac{C_B \sin \theta_3}{C_3 \sin \theta_B} + \cos^2 \theta_3 - \sin^2 \theta_3 \right. \\
& \left. - (\cos^2 \theta_B - \sin^2 \theta_B) \frac{C_B \sin \theta_3}{C_3 \sin \theta_B} \right] \\
& + \frac{DB(2) \sin \theta_3}{\cos^3 \theta_3} \left( \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3} \right) \left[ \sin \theta_3 \cos \theta_3 - \sin \theta_B \cos \theta_B \right] \\
& + \frac{DB}{\cos^2 \theta_3} \left( \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3} \right) \left[ \cos^2 \theta_3 - \sin^2 \theta_3 - (\cos \theta_B \cos \theta_3) \frac{C_B \sin \theta_3}{C_3 \sin \theta_B} \right. \\
& \left. + \sin \theta_B \sin \theta_3 \right], \quad (279)
\end{aligned}$$

$$\begin{aligned}
\frac{dR}{d\theta_1} = & -\frac{D_1}{\sin^2 \theta_1} + \frac{DA C_3 \sin \theta_1}{C_1 \sin \theta_3} \left( \frac{\sin \theta_3}{\cos^3 \theta_3} \right) \left[ \theta_3 - \theta_B + \sin \theta_3 \cos \theta_3 \right. \\
& \left. - \sin \theta_B \cos \theta_B \right] \\
& + \frac{DA C_3 \sin \theta_1}{2 C_1 \sin \theta_3} \left[ 2 - \frac{C_B \sin \theta_3}{C_3 \sin \theta_B \cos^2 \theta_3} - \left( \frac{C_B}{C_3} \right)^3 \frac{\sin \theta_3}{\sin \theta_B} \right. \\
& \left. + \frac{C_B \sin \theta_3 \sin^2 \theta_B}{C_3 \sin \theta_B \cos^2 \theta_3} \right] \\
& + \frac{DB C_3 \sin \theta_1}{C_1 \sin \theta_3 \cos \theta_3} \left[ \frac{2 \sin^2 \theta_3}{\cos \theta_3} - \frac{2 \sin \theta_3 \sin \theta_B}{\cos \theta_3} \right. \\
& \left. + \frac{\cos^2 \theta_3 - \sin^2 \theta_3}{\cos \theta_3} - \frac{C_B \sin \theta_3 \cos \theta_B}{C_3 \sin \theta_B} + \frac{\sin \theta_B \sin \theta_3}{\cos \theta_3} \right], \quad (280)
\end{aligned}$$

$$\begin{aligned}
\frac{dR}{d\theta_1} = & \frac{-D1}{\sin^2 \theta_1} + \frac{DA C_3 \sin \theta_1}{C_1 \sin \theta_3} \left( \frac{\sin \theta_3}{\cos^3 \theta_3} \right) \left[ \theta_3 - \theta_B + \sin \theta_3 \cos \theta_3 - \sin \theta_B \cos \theta_B \right] \\
& + \frac{DA C_3 \sin \theta_1}{2 C_1 \sin \theta_3} \left[ 2 - \frac{C_B \sin \theta_3}{C_3 \sin \theta_B} \left( \frac{\sin^2 \theta_B - 1}{\cos^2 \theta_3} \right) - \left( \frac{C_B}{C_3} \right)^3 \frac{\sin \theta_3}{\sin \theta_B} \right] \\
& + \frac{DB C_3 \sin \theta_1}{C_1 \sin \theta_3 \cos \theta_3} \left[ \frac{1 - \sin \theta_3 \sin \theta_B}{\cos \theta_3} - \frac{C_B}{C_3} \frac{\sin \theta_3 \cos \theta_B}{\sin \theta_B} \right].
\end{aligned}
\tag{281}$$

$$\begin{aligned}
\frac{dR}{d\theta_1} = & \frac{-D1}{\sin^2 \theta_1} + \frac{DA C_3 \sin \theta_1}{C_1 \sin \theta_3} \left( \frac{\sin \theta_3}{\cos^3 \theta_3} \right) \left[ \theta_3 - \theta_B + \sin \theta_3 \cos \theta_3 - \sin \theta_B \cos \theta_B \right] \\
& + \frac{DA C_3 \sin \theta_1}{C_1 \sin \theta_3} \left[ 1 + \frac{C_B \sin \theta_3}{2 C_3 \sin \theta_B} \left( \frac{-\cos^2 \theta_B}{\cos^2 \theta_3} \right) - \left( \frac{C_B}{C_3} \right)^3 \frac{\sin \theta_3}{2 \sin \theta_B} \right] \\
& + \frac{DB C_3 \sin \theta_1}{C_1 \sin \theta_3 \cos \theta_3} \left[ \frac{1}{\cos \theta_3} - \sin \theta_3 \left( \frac{\sin \theta_B}{\cos \theta_3} + \left( \frac{C_B}{C_3} \right)^2 \frac{\cos \theta_3}{\sin \theta_B} \right) \right].
\end{aligned}
\tag{282}$$

$$\begin{aligned}
\frac{dR}{d\theta_1} = & \frac{-D1}{\sin^2 \theta_1} + \frac{C_3 \sin \theta_1}{C_1 \sin \theta_3} \left\{ DA \left[ \frac{\sin \theta_3}{\cos^3 \theta_3} \left( \theta_3 - \theta_B + \sin \theta_3 \cos \theta_3 - \sin \theta_B \cos \theta_B \right) \right. \right. \\
& + \left. \left. \left( 1 - \left( \frac{C_B}{C_3} \right)^3 \frac{\sin \theta_3}{\sin \theta_B} \right) \right] \right. \\
& + \left. \left. \frac{DB}{\cos \theta_3} \left[ \frac{1}{\cos \theta_3} - \sin \theta_3 \left( \frac{\sin \theta_B}{\cos \theta_3} + \left( \frac{C_B}{C_3} \right)^2 \frac{\cos \theta_3}{\sin \theta_B} \right) \right] \right\}.
\end{aligned}
\tag{283}$$

This is the expression in Subroutine Base for DRDT where the quantity inside braces is DRDT3,  $\theta_1$  = BSA and other angles and their functions are as mentioned above in discussing this subroutine.

$R = D1/\tan H$  gives the range in terms of TH.

$$BSGI(J) = \sqrt{\frac{\cos \theta_1}{R \sin \theta_1 \left| \frac{dR}{d\theta_1} \right|}} \quad (284)$$

is the geometric spreading loss factor.

#### ARC LENGTH

is found in a manner similar to that in Subroutine REFR but with use of  $\theta_B$  for the lower limit in equation (23) of Spofford et al. (1982) corresponding to the basement reflection angle. This gives

$$\begin{aligned} BSLS = \frac{DL}{\alpha_0 FK} = & \frac{2C_3}{\alpha_0 g_0 (1+B) \cos \theta_3} \left[ \frac{-\gamma C_3^2}{6\sigma \cos^3 \theta_3} (\sin^3 \theta_3 - \sin^3 \theta_B) \right. \\ & + \frac{B\gamma C_3^2 + 2\gamma \nu C_3}{4\sigma \cos^2 \theta_3} (\sin \theta_3 \cos \theta_3 - \sin \theta_B \cos \theta_B) \\ & + \left( \frac{\gamma C_3^2}{2\sigma \cos^3 \theta_3} + \frac{\gamma(\nu^2 - \mu) + 2\alpha_0 \sigma + B\nu \gamma}{2\sigma \cos \theta_3} \right) (\sin \theta_3 - \sin \theta_B) \\ & \left. + \left( \frac{B\gamma C_3^2 + 2\gamma \nu C_3}{4\sigma \cos^2 \theta_3} + \frac{B\gamma(\nu^2 - \mu)}{2\sigma} + B\alpha_0 \right) (\theta_3 - \theta_B) \right] \end{aligned}$$

#### TRAVEL TIME

is found as in Subroutine REFR with  $\theta_B$  substituted as the lower limit in the equation for TS, equation (22) of Spofford et al. (1982).

$$T = \frac{D1}{C_1 \sin \theta_1} + \frac{2}{g_0 (1+B)} \left[ \frac{\sin \theta_3 - \sin \theta_B}{\cos \theta_3} + B \ln \left( \frac{\cos \theta_3}{1 - \sin \theta_3} \right) - B \ln \left( \frac{\cos \theta_B}{1 - \sin \theta_B} \right) \right] \quad (286)$$

and by the identity mentioned in Subroutine REFR

$$BST(J) = \frac{D5}{\sin \theta_1} + D4 \left[ \frac{\sin \theta_3 - \sin \theta_B}{\cos \theta_3} + \frac{B}{2} \ln \left( \frac{1 + \sin \theta_3}{1 - \sin \theta_3} \right) \left( \frac{1 - \sin \theta_B}{1 + \sin \theta_B} \right) \right] \quad (287)$$

The computations in this subroutine are made in 1 degree steps for all applicable angles.

RETURN

END (of SUBROUTINE BASE) (Go back to main program.)

### SUBROUTINE LOSS (JJ)

Discussion. This supplements section III.C. Simulated Bottom Loss, as set forth in Spofford et al.(1982).

Other subroutines provide for computations of travel time for base path, angles, reflection and transmission coefficient factors, surface scattering travel time differences, etc. which are needed in this subroutine.

For a base path travel time of  $T_{K,1}$  the three other paths have travel times

$$T_{K,2} = T_{K,1} + (2ZS/CS) \sin \theta_S \quad (288)$$

$$T_{K,3} = T_{K,1} + (2ZR/CS) \sin \theta_S \quad (289)$$

$$T_{K,4} = T_{K,1} + (2ZS/CS) \sin \theta_S + (2ZR/CS) \sin \theta_S \quad (290)$$

The travel time differences are converted to phase shifts, and the paths acquire additional phase shifts for surface reflections of  $-\pi$ ,  $\pi$ , and  $2\pi$  radians respectively. The subroutine accounts for all these effects by treating the surface scattering travel time interference "artifact" as a separate factor.

It is assumed the frequency averaged intensity ratio is given by

$$\left\langle \frac{I}{I_0} \right\rangle = \frac{1}{F_2 - F_1} \int_{F_1}^{F_2} P^* P dF \quad (291)$$

where

P represents the sound pressure and F is the frequency.

Ordinarily one assumes a superposition of waves results in pressure

$$P = \sum_K A_K e^{i\phi_K} \text{ so one would write } P^* P = \left( \sum_K A_K^* e^{-i\phi_K} \right) \left( \sum_L A_L e^{i\phi_L} \right), \quad (292)$$

$$\text{but in this model it is assumed } P = \sum_K A_K \sum_j e^{i\phi_{K,j}} \quad (293)$$

where some justification is by Spofford et al.(1982).



If we include the frequency dependence in  $\phi_{k,j}$  so this represents phase per unit frequency we get

$$p^*p = \sum_{k,L} A_L^* A_K \sum_j e^{i\phi_{L,j}^* F} e^{i\phi_{K,j} F} \quad (294)$$

and

$$\left\langle \frac{I}{I_0} \right\rangle = \frac{1}{F_2 - F_1} \int_{F_1}^{F_2} \sum_{k,L} A_L^* A_K \sum_j e^{i(\phi_{K,j} - \phi_{L,j}^*) F} dF. \quad (295)$$

Now let  $\langle A_L^* A_K \rangle$  be the frequency averaged products of amplitudes; they can be factored out of the integral, and note  $F_2 - F_1 = F_1$  for 1 octave bandwidth, so

$$\left\langle \frac{I}{I_0} \right\rangle = \frac{1}{F_1} \sum_{k,L} \langle A_L^* A_K \rangle \sum_j \int_{F_1}^{F_2} e^{i(\phi_{K,j} - \phi_{L,j}^*) F} dF. \quad (296)$$

$$\left\langle \frac{I}{I_0} \right\rangle = \frac{1}{F_1} \sum_{k,L} \langle A_L^* A_K \rangle \sum_j \left[ \frac{e^{i(\phi_{K,j} - \phi_{L,j}^*) F_2} - e^{i(\phi_{K,j} - \phi_{L,j}^*) F_1}}{i(\phi_{K,j} - \phi_{L,j}^*)} \right]. \quad (297)$$

For paths in the sediment the phases are assumed to be complex and written

$\phi_K = 2\pi(t + i\alpha_0 S)$  with  $t$  the time in the sediment (plus surface scattering travel (298)

time difference),  $\alpha_0$  the absorption coefficient, and  $S$  the effective path

length in the sediment. The exponential terms account for absorption in the

sediment. But for layer-reflected paths it is assumed there is no absorption

and the imaginary part is zero. Thus the phases are real and contributions

from these paths are

(299)

$$\frac{1}{F_1} \sum_{k,L} \langle A_L^* A_K \rangle \sum_j \left[ \frac{\sin(\phi_{K,j} - \phi_{L,j}) F_2 - \sin(\phi_{K,j} - \phi_{L,j}) F_1}{\phi_{K,j} - \phi_{L,j}} \right].$$

Consider the first sum. For layer-reflected rays of unit incident amplitude, the reflected amplitude is simply taken to be the reflection coefficient,  $V$ , and intensity is  $V^*V$ . The frequency averaged value of  $V^*V$  is desired. It is obtained by computing the values of  $V^*V$  at eight different frequencies over a one octave range and finding the numerical average. The number of values used in the average evidently is arbitrarily chosen to be eight.

Consider the second sum. Four bottom interacting reflected pulses reach the receiver from the source in some order arbitrarily chosen, for example, on a time scale as illustrated.



The sum includes all combinations of travel time differences such as:

<u>K,L</u>	<u>Phase Shift/F</u>	<u>Surface reflection at</u>
1-2	DR	receiver
1-3	DS	source
1-4	DS + DR	source and receiver
2-3	DS - DR	source and receiver
2-4	DS	source
3-4	DR	receiver

The frequency averaged sum is

$$\frac{4}{2F_1} \left[ \frac{\sin F_2(DR+DS) - \sin F_1(DR+DS)}{DR+DS} + \frac{\sin F_2(DS-DR) - \sin F_1(DS-DR)}{DS-DR} \right. \\ \left. - 2 \frac{\sin F_2 DS - \sin F_1 DS}{DS} - 2 \frac{\sin F_2 DR - \sin F_1 DR}{DR} \right] \quad (300)$$

for the layer reflected paths. The terms corresponding to only one surface reflection are given negative signs to account for a phase shift of  $\pi$  radians while those corresponding to two reflections have positive signs to account for a phase shift of  $2\pi$  radians. The terms corresponding to no phase shift are accounted for by adding the numeral 4 to this sum. The sum just mentioned is multiplied by the frequency averaged value of  $V*V$ . This accounts for the layer reflected ray intensities.

Next the layer transmitted rays are accounted for by computing the layer two-way transmission coefficient at the center frequency of the octave wide

band and multiplying by the basement reflection coefficient (where appropriate) and the geometrical spreading loss factor. This gives the amplitude of the transmitted rays. No further frequency averaging is done for transmitted path amplitudes.

The phases of the four layer-transmitted signals are accounted for by changing the signs of two of the amplitudes which is equivalent to changing the phases by  $\pi$  radians to account for one surface reflection each and no change of the other two to account for phase change of zero for the bottom-reflected-only path and phase change of  $2\pi$  for the twice-surface-reflected path. In addition, phase shifts and attenuation in the sediment are accounted for by forming complex frequency dependent phases as follows:

$$\phi_1 = 2\pi(t + i\alpha_0 S), \quad (301)$$

$$\phi_2 = 2\pi(t + t_s + i\alpha_0 S), \quad (302)$$

$$\phi_3 = 2\pi(t + t_R + i\alpha_0 S), \quad (303)$$

$$\phi_4 = 2\pi(t + t_s + t_R + i\alpha_0 S), \quad (304)$$

where  $t$  is base ray travel time,  $t_R$  and  $t_s$  are surface scattering travel time differences,  $\alpha_0$  is the sediment attenuation coefficient, and  $S$  is the sediment path length. These phase factors account for attenuation in the sediment. Products of amplitudes are formed as are the exponential phase factors and their integrals are summed as needed to produce the transmitted ray portion of  $\langle \frac{I}{I_0} \rangle$ .

The reflected and transmitted frequency averaged intensities are combined incoherently to find the total loss which would be measured,  $L = -10 \log \langle I/I_0 \rangle$ , (305, equation (43) of Spofford et al. (1982)).

The computed spreading loss is given most simply by

$$L_0 = -10 \log_{10} \frac{4}{(\text{slant range})^2} = -10 \log_{10} \frac{4}{\left(\frac{R}{\cos \theta}\right)^2} \quad (306)$$

which represents a sum of 4 unit initial intensity rays.

Therefore, bottom loss is found by subtraction

$$\begin{aligned} BL &= L - L_0, \\ &= -10 \log \left\langle \frac{I}{I_0} \right\rangle - \left[ -10 \log \frac{4}{\left(\frac{R}{\cos \theta}\right)^2} \right] \end{aligned} \quad (307)$$

$$= -10 \log \left[ \frac{\left\langle \frac{I}{I_0} \right\rangle}{4 \left(\frac{\cos \theta}{R}\right)^2} \right] = A_{LOSS}. \quad (308)$$

Suitable variations in computational procedures are made in order to suit the various domains to be accounted for.

Now consider SUBROUTINE LOSS(JJ).

ALPH0 =  $\frac{\ln 10}{4\pi(10000)}$  ALPH9 is used to convert the usual logarithmic expression in dB/m/kHz from the COMMON block to suitable units for use in an exponential form.

EX =  $\log_{10} e$  is defined.

Aim = (0+i) used to provide imaginary quantities.

$F_1 = F/\sqrt{2}$  is the lower limit and (309)

$F_2 = F\sqrt{2}$  is the upper limit of a one octave bandwidth centered at F. (310)

$FPI2D = \frac{4\pi FD}{C_2}$  Thickness of the layer is D and sound speed in the layer is  $C_2$ . (311)

NAV1=8 is defined.

$FPIINC = \frac{FPI2D(\sqrt{2} - 1/\sqrt{2})}{NAV1} = \frac{4\pi D}{C_2} \frac{(F_2 - F_1)}{8}$  is an increment (312)

$FPIIN = \frac{4\pi D}{C_2} F - \frac{(8-1)}{2} \frac{4\pi D}{8C_2} (F_2 - F_1)$  (313)

$= \frac{4\pi D}{C_2} \left( F - \frac{7}{16} (F_2 - F_1) \right)$  (314)



This is an increment to be used in computing frequency dependent phases for reflection and transmission coefficients. Consider a one octave bandwidth centered at frequency  $F(JJ)=F$  with lower and upper limits  $F_1$  and  $F_2$ . The term  $FPIIN$  is used to compute a quantity at the frequency  $F_c = F - \frac{7(F_2 - F_1)}{16}$  (315) as illustrated in figure 17.



Figure 17. Frequencies for computation of average in a one-octave wide band.

This is the starting frequency for computing frequency averaged reflection and transmission coefficients.

$NTHC = \theta_c$  the caustic angle in degrees

$N = 90 - \theta_c$

COMPUTE LOSS FOR ANGLES ABOVE CRITICAL

(the caustic angle). These calculations apply to the domain of range  $R_3$  as shown in figure 2.

DO 10 I = 1,90

10 ALOSS(JJ,I)=25 This puts in an assumed value.

DO 100 I=1,N

J = 91-I Computations are made for angles in steps of 1 degree from  $\theta_c$  to  $90^\circ$ .

$FPIAUX = FPIIN$  Use in starting the frequency average calculation.

DO 20 NAV=1,NAV1 Calculation is made for 8 frequencies within the one octave bandwidth.

$$ALPH2 = \alpha_2 = \frac{4\pi D}{C_2} \left[ F - \frac{7}{16} (F_2 - F_1) \right] \sin \theta_2 \quad (316)$$

is a frequency and path dependent phase angle for the layer.

$$\left. \begin{aligned} C &= \cos \alpha_2 \\ S &= \sin \alpha_2 \end{aligned} \right\} \quad \text{Used in computing the square of the layer reflection coefficients.}$$

The square of the layer reflection coefficient is needed because we want the intensity of the reflected wave which is proportional to the layer reflection coefficient, or equal to it for an incident wave of unit intensity.

The layer reflection coefficient, equation (30) of Spofford et al. (1982) is

$$R = \frac{V_{12} + V_{23} e^{2i\alpha d}}{1 + V_{12}V_{23}e^{2i\alpha d}} \quad \text{and if we let } \alpha_2 = 2\alpha d \quad (317)$$

$$\begin{aligned} R^*R &= \left( \frac{V_{12} + V_{23} e^{-i\alpha_2}}{1 + V_{12}V_{23}e^{-i\alpha_2}} \right) \left( \frac{V_{12} + V_{23} e^{i\alpha_2}}{1 + V_{12}V_{23}e^{i\alpha_2}} \right) \\ &= \frac{V_{12}^2 + V_{23}^2 + V_{32}V_{12}(e^{i\alpha_2} + e^{-i\alpha_2})}{1 + V_{12}^2V_{23}^2 + V_{12}V_{23}(e^{i\alpha_2} + e^{-i\alpha_2})} \\ &= \frac{V_{12}^2 + 2V_{32}V_{12}\cos\alpha_2 + V_{23}^2}{1 + V_{12}^2V_{23}^2 + 2V_{12}V_{23}\cos\alpha_2} \\ &= \frac{(V_{12} + V_{23}\cos\alpha_2)^2 + (V_{23}\sin\alpha_2)^2}{(1 + V_{12}V_{23}\cos\alpha_2)^2 + (V_{12}V_{23}\sin\alpha_2)^2} \quad (318) \end{aligned}$$

Interchanging subscripts changes signs of the factors but has no effect on the value of  $R^*R$  so doing this and introducing prefix  $R$  we find

$$VV = R^*R = \frac{(RV_{21} + RV_{32}\cos\alpha_2)^2 + (RV_{32}\sin\alpha_2)^2}{(1 + RV_{21}RV_{23}\cos\alpha_2)^2 + (RV_{21}RV_{32}\sin\alpha_2)^2} \quad (319)$$

as in Subroutine LOSS. The boundary reflection coefficients  $RV_{21}$ ,  $RV_{32}$  are computed in Subroutine REFL.

AUX=AUX+VV      The value of VV is computed and the results summed.

FPIAUX = FPIAUX + FPIINC causes increment in frequency to the next step shown in figure 17 and computation of VV again.

20 CONTINUE. Procedure is completed 8 times yielding a sum of 8 values of VV.

$VV = AUX/NAV1 = \frac{VV(Fc) + \dots + VV(Fc8)}{8}$  gives an average value of VV, the squared

reflection coefficient, over the 1 octave frequency band as illustrated in figure 17.

$DR = 2\pi RDTR(J)$   
 $DS = 2\pi RDTS(J)$

converts surface scattering travel time differences so when multiplied by frequency gives phase shift in radians. (320)

DT The first four consecutive DT statements provide the sum of frequency averaged phases for the layer reflected waves as described in the Discussion.

The fifth DT statement provides the sum multiplied by the frequency averaged reflection coefficient to obtain the intensity of the layer-reflected rays.

For basement reflected paths the separate ray contributions are summed incoherently on the assumption that the time delays between layer and basement reflected paths results in incoherent arrivals at the receiver.

$ALPH2 = FPI2D * BSSIN2(J) / 2 = \frac{4\pi F(JJ)}{C_2} \frac{\sin \alpha_2}{2} = \alpha_2$  gives phase shift for 1 way travel (321)

in the layer.

$C = \cos \alpha_2$

$S = \sin \alpha_2$

The two-way travel layer-transmission coefficient can be obtained as shown for SUBROUTINE GEOPHYS:

$$T = \frac{16 A_1 A_3 \left( \frac{A_2}{(A_3 + A_2)(A_2 + A_1)} \right)^2}{1 + 2 V_{32} V_{21} \cos 2\alpha_2 + (V_{32} V_{21})^2} \quad (322)$$

where we have in the numerator the expression for BSTRF. Consider the

denominator of this expression. It has the form  $1 + 2M \cos 2\alpha_2 + M^2$ , where (323)

$M = V_{32} V_{21}$ , so by using identities we can write:

$$\sin^2 \alpha_2 + \cos^2 \alpha_2 + 2M(\cos^2 \alpha_2 - \sin^2 \alpha_2) + M^2(\sin^2 \alpha_2 + \cos^2 \alpha_2) \quad (324)$$

$$= \cos^2 \alpha_2 (1 + 2M + M^2) + \sin^2 \alpha_2 (1 - 2M + M^2) \quad (325)$$

$$= (1 + M)^2 \cos^2 \alpha_2 + (M - 1)^2 \sin^2 \alpha_2 \quad (326)$$

$$= [(1 + M) \cos \alpha_2 + i(M - 1) \sin \alpha_2]^2 \quad (327)$$

Substitution of this expression for the denominator gives

$$V = \frac{BSTF}{[(1 + BSV32 BSV21) \cos \alpha_2 + i (BSV32 BSV21 - 1)^2]} \quad (328)$$

The quantities with prefix BS come from SUBROUTINE BASE.

The amplitude of a ray reflected by the basement after passing through the

layer into the water is given by  $VV = |V| \sqrt{\frac{\cos \theta_1}{R \sin \theta_1 \left| \frac{dR}{d\theta_1} \right|}} (REF) \quad (329)$

where  $BSG1(J) = \sqrt{\frac{\cos \theta_1}{R \sin \theta_1 \left| \frac{dR}{d\theta_1} \right|}}$  is the geometric spreading factor and (REF)  $(330)$  is a numerical basement pressure reflection coefficient.

AUX = 0 is defined.

IF VV=0 GO TO 120 accounts for the case of no basement reflection.

The amplitudes of the basement reflected waves are designated

$$BR(1) = VV$$

$$BR(2) = -VV$$

$$BR(3) = -VV$$

$$BR(4) = VV$$

The negative signs are to augment phases by  $\pi$  radians for 1 surface reflection and the positive signs account for zero and  $2\pi$  radian phase shifts for no surface and two surface reflections respectively.

$$V = (BST(J) + i\alpha_0 BSLS(J)) = (t + i\alpha_0 S) \quad (331)$$

is used to form the complex frequency

dependent phases mentioned in the Discussion as follows:

$$PH(1) = \phi_1 = 2\pi(t + i\alpha_0 S) \quad (332)$$

$$PH(2) = \phi_2 = 2\pi(t + t_s + i\alpha_0 S) \quad (333)$$

$$PH(3) = \phi_3 = 2\pi(t + t_R + i\alpha_0 S) \quad (334)$$

$$PH(4) = \phi_4 = 2\pi(t + t_R + t_s + i\alpha_0 S) \quad (335)$$

Here  $BST(J) = t$  is the travel time in water plus time in the sediment,  $t_R$  and  $t_s$  are surface scattering travel time differences, and  $ALPH0 * BSLS(J)$  is the attenuation loss per unit frequency in the sediment  $= \alpha_0 S$  where  $S$  is the "effective" path length. These are complex phase factors.



$V = 0$  is defined.

· D0110 K=1,3 to 110 CONTINUE produces  $AUX=BR(K)*BR(L)$  i.e. cross products of the amplitudes of the transmitted rays for all permitted combinations and  $AUX1=(PH(K)-CONJG(PH(L)))*AIM$

$=i(\phi_k - \phi_L^*)$  the corresponding complex phase differences.

IF (REAL(AUX1)\*F2 < -40) GO TO 110 causes terms like  $4\pi\alpha_0 SF_2$  to be ignored unless greater than -40 (Note that  $e^{-40} \approx 10^{-17}$ ) in which case

$$V = V + BR(K)*BR(L) \frac{e^{iF_2(\phi_k - \phi_L^*)} - e^{iF_1(\phi_k - \phi_L^*)}}{i(\phi_k - \phi_L^*)} \quad (336)$$

Here we have terms applicable to the transmitted rays like those in the formula for the frequency averaged intensity ratio shown in the Discussion of this subroutine. Terms of this kind are generated and summed.

$AUX = 2*REAL(V) = 2ReV$  gives the effective value of the intensity of the cross product terms for the four contributing paths.

·  $AUX2 = -2(2\pi)\alpha_0 S$

IF  $AUX2*F2 = -4\pi\alpha_0 SF_2 < -40$  go to 120 causes terms like  $-4\pi\alpha_0 SF_2$  to be ignored unless greater than -40 in which case

$$AUX = 2ReV + \frac{4(e^{-4\pi\alpha_0 SF_2} - e^{-4\pi\alpha_0 SF_1})}{-4\pi\alpha_0 S} [BR(1)]^2 \quad (337)$$

The last term accounts for dissipation loss along the path in the sediment for four rays with initial intensities of the same amount,  $[BR(1)]^2 = (VV)^2$ , combined incoherently.

$$120 \quad DT = DT + \frac{\left[ 2ReV + \frac{4(e^{-4\pi\alpha_0 SF_2} - e^{-4\pi\alpha_0 SF_1})}{-4\pi\alpha_0 S} (VV)^2 \right]}{F_1 \left[ 4 \left( \frac{\cos \Theta}{R} \right)^2 \right]} \quad (338)$$

On the right-hand side of the last equation DT represents the frequency averaged effects of the layer-reflected rays and in the second term  $2\text{Re}V$  gives the effects of the cross product terms for the transmitted rays while the last term gives the effects of the frequency averaged attenuation in the sediment on the 4 rays with intensities  $(VV)^2$ . In the denominators the factors  $F1$  and  $4\pi\alpha_0 S$  are needed for the frequency averaging and the  $4 (\cos\theta/R)^2$  is the geometric intensity sum for 4 rays with  $R/\cos\theta$  as the slant range. The last step gives the bottom loss for angles above the caustic:

$\text{ALOSS}(JJ,J) = -10 \log_{10}(DT).$

CONTINUE

NMAX=91-N is definition.

COMPUTE LOSS FOR ANGLES BETWEEN TIR AND THS.

This applies to the domain designated by  $R_1$  in figure 2, i.e. for angles between THS=SAP the smallest bottom grazing angle or TIR the angle of total internal reflection, whichever is greater, and the basement limiting angle.

Previously we had  $N=90-\text{NTHC}$

$\text{NMAX}=91-90+\text{NTHC}=1+\text{NTHC}$

$\text{NTIR}=\text{TIR}+1$  gives angle in degrees.

$N=\text{NMAX}-\text{NTIR}$

$N=1+\text{NTHC}-\text{NTIR}-1=\text{NTHC}-\text{NTIR}$  redefines N

DO 200 I=1,N=1,NTHC-NTIR

$J=\text{NMAX}-1=\text{NTHC}$  is maximum value of J while the minimum value is  $1+\text{NTIR}$  or NSAP.

IF ( $J < \text{NSAP}$ ) go to 800 causes computation for angles between TIR and THS as stated. Otherwise, for rays in domain  $R_2$  shown in figure 2, the following is done:

COMPUTE REFLECTION COEFFICIENT

COMPUTE FREQ AVERAGE ABSOLUTE REFLECTION

From here to the statement  $VV=AUX/NAV1$  the frequency averaged squared reflection coefficient  $VV$  is computed as for the case of angles above the caustic in this subroutine.

$$ALPH2=FPI2D*RSIN2(J)=\frac{4\pi DF(JJ)\sin\theta_2}{C_2}=\alpha_2$$

Compute new  $\alpha_2$ , using the band center frequency to find a new  $V$ .

$$C=\cos \alpha_2$$

$$S=\sin \alpha_2$$

$$V=\frac{RV21+RV32\cos\alpha_2+i RV32\sin\alpha_2}{(1+RV21 RV32\cos\alpha_2+i RV21 RV32\sin\alpha_2)} \sqrt{VV} \left( \frac{\cos\theta_1}{R_1} \right) \quad (339)$$

$$\frac{RV21+RV32\cos\alpha_2+i RV32\sin\alpha_2}{1+RV21 RV32\cos\alpha_2+i RV21 RV32\sin\alpha_2}$$

Here the first term contains the new  $\alpha_2$  calculated for the band center frequency, and it gives proportional values of real and imaginary parts of the complex layer reflection coefficient while the second term,  $\sqrt{VV}$ , gives the magnitude, and the last term is the geometric amplitude factor. Thus  $V$  is the complex amplitude of the layer reflected ray. This is used to obtain a coherent sum of contributions from the 4 paths for this angular domain.

$$\left. \begin{array}{l} AR(1)=V \\ AR(2)=-V \\ AR(3)=-V \\ AR(4)=V \end{array} \right\} \quad \begin{array}{l} \text{These give amplitudes of the four layer reflected} \\ \text{paths including effects of phase shifts upon surface} \\ \text{reflection.} \end{array}$$

$$\left. \begin{array}{l} PH(1) = 2\pi t \\ PH(2)=2\pi(t+t_S) \\ PH(3)=2\pi(t+t_R) \\ PH(4)=2\pi(t+t_R+t_S) \end{array} \right\} \quad \begin{array}{l} \text{Here } RT(S)=t \text{ is travel time in the water for the} \\ \text{reflection path, } RDT(S)=t_S, \text{ } RDTR(J)=t_R \text{ appropriate} \\ \text{to this path.} \end{array}$$

COMPUTE BIG TRANSMISSION COEFFICIENT

This applies to path R2.C. of figure 2.

AR(5)=0

AR(6)=0

AR(7)=0

AR(8)=0

Sets array = 0

The layer transmission coefficient factor BTRF for the Big Angle ray is needed as computed in SUBROUTINE REFR.

IF BTRF=0 GO TO 205

Skip Big Angle computation

IF BT(S) RT(J) GO TO 205

for physically unrealistic cases.

Here BT is total travel time and RT is travel time in water.

$ALPH2 = \alpha_2 = \frac{4\pi DF(JJ)}{c_2} \frac{\sin \theta_2}{2}$  where  $\theta_2$  is the angle in the layer for the big

angle case and  $\alpha_2$  is the phase factor for transmission one way through the layer.

$$V = \frac{16 A_1 A_3 \left( \frac{A_2}{(A_3 + A_2)(A_2 + A_1)} \right)^2 \sqrt{\frac{\cos BA}{\sin BA \left| \frac{dR}{dBA} \right|}}}{\left[ (1 + BV32BV21) \cos \alpha_2 + i (BV32BV21 - 1) \sin \alpha_2 \right]^2} \quad (340)$$

This is the two-way transmission coefficient for paths refracted in the sediment multiplied by the geometric spreading factor.

AR(5)=V

AR(6)=-V

AR(7)=-V

AR(8)=V

These are amplitudes for sediment refracted paths including effects of surface reflections on phases.

$V = BT(J) + i\alpha_0 BLS(J)$

(341)

$V = t + i\alpha_0 S_c$  the total travel time for path with bottom grazing angle BA = Big Angle plus dissipation loss per unit frequency in sediment. (342)



$$PH(5) = 2\pi(t + i\alpha_0 S_c)$$

(343)

$$PH(6) = 2\pi(t + t_s + i\alpha_0 S_c)$$

(344)

$$PH(7) = 2\pi(t + t_R + i\alpha_0 S_c)$$

(345)

$$PH(8) = 2\pi(t + t_s + t_R + i\alpha_0 S_c)$$

(346)

These are the complex phase factors including effects of surface scattering travel times and dissipation loss factors for this case.

CONTINUE

COMPUTE SMALL TRANSMISSION COEFFICIENT

This applies to path R2.b. of figure 2. Here the computation is exactly the same as for the Big Angle case but using appropriate factors for the Small Angle case. One exception occurs. The transmission coefficient is made negative imaginary:

$$V = -V * SGI(J) * AIM = -iV \sqrt{\frac{\cos SA}{R \sin SA} \left| \frac{dR}{dSA} \right|} \quad (347)$$

This should account for a (controversial) phase change due to the caustic in the sediment shown in figure 2 for ray R2.b. and mentioned on page 56 of Spofford et al. (1982).

The amplitudes and phases are computed as in the Big Angle case.

COMPUTE BASEMENT RAY TRANSMISSION COEFFICIENT.

This applies to path R2.d. of figure 2.

The same procedure is used as for the Big and Small Angle coefficients. We get the amplitudes of the transmitted rays by multiplying the transmission coefficients by the geometric spreading factor and the basement reflection coefficient REF. This accounts for ray R2.d. in figure 2.

Amplitudes and phase factors are computed as before in this subroutine.

The rest of the computations are done in a similar manner as before except for differences in notation.

DO 210, K=1, 15

NA=K+1

DO 210, L=NA, 16

AUX 99=AR(K)\*CONJG(AR(L))

=AR(K) AR\*(L) computes cross products of complex amplitudes for all three cases of angles from caustic to basement limiting.

IF |AUX99| = 0 GO TO 210

AUX 1=i( $\phi_K - \phi_L^*$ ) computes complex phase differences.

IF REAL (AUX1)\*F2 < -40 GO TO 210 causes terms like  $4\pi\alpha_0 S_d F_2$  to be ignored unless greater than -40 in which case the sum is computed.

$$V = V + AR(K)AR^*(L) \frac{e^{iF_2(\phi_K - \phi_L^*)} - e^{iF_1(\phi_K - \phi_L^*)}}{i(\phi_K - \phi_L^*)} \quad (348)$$

This makes a sum of contributions from the Small Angle path, Big Angle path and basement reflected path.

CONTINUE to 209.

AUX=2\*REAL(V) gives the average value of a complex quantity representing the sum of contributions from the four paths.

IF |AR(13)| = 0 go to 209 Skip next computation unless transmitted contribution of basement ray intensity > 0.

AUX 2=- $4\pi\alpha_0 S_d$  is effective path length for basement reflected ray in sediment.

IF - $4\pi\alpha_0 S_d F_2$  < -40 GO TO 209 Ignore contributions < -40.

$$AUX=2\text{Re}V+(4) \frac{e^{-4\pi\alpha_0 S_d F_2} - e^{-4\pi\alpha_0 S_d F_1}}{-4\pi\alpha_0 S_d} |V|^2 \quad (349)$$

gives contributions for basement reflected paths.

AUX2 =  $-4\pi\alpha_0 S_c$ ,  $S_c$  is effective path length in sediment for Big Angle path.

IF  $-4\pi\alpha_0 S_c F_2 < -40$  TO 211 } Ignore contributions too small to be physically realistic. (350)

IF AR(5) = 0 GO TO 211

$$\text{AUX} = 2 \text{Re} V + (4) \frac{e^{-4\pi\alpha_0 S_d F_2} - e^{-4\pi\alpha_0 S_d F_1}}{-4\pi\alpha_0 S_d} + (4) \frac{e^{-4\pi\alpha_0 S_c F_2} - e^{-4\pi\alpha_0 S_c F_1}}{-4\pi\alpha_0 S_c} \quad (351)$$

adds contributions for ray along Big Angle path.

AUX2=  $-4\pi\alpha_0 S_b$ ,  $S_b$  is effective path length in sediment for Small Angle path.

IF  $-4\pi\alpha_0 S_b F_3 < -4060$  TO 212.

Ignore contributions that are not

IF AR(9) = 0 GO TO 212.

physically realistic.

(352)

$$AUX = 2\text{Re}V + (4) \frac{e^{-4\pi\alpha_0 S_d F_2} - e^{-4\pi\alpha_0 S_d F_1}}{-4\pi\alpha_0 S_d}$$

$$+ (4) \frac{e^{-4\pi\alpha_0 S_c F_2} - e^{-4\pi\alpha_0 S_c F_1}}{-4\pi\alpha_0 S_c}$$

$$+ (4) \frac{e^{-4\pi\alpha_0 S_b F_2} - e^{-4\pi\alpha_0 S_b F_1}}{-4\pi\alpha_0 S_b}$$

(353)

adds contributions for ray along Small Angle path.

$$AUX = \frac{AUX}{F_1} + 4 |AR(1)|^2$$

(354)

The first term,  $\frac{AUX}{F_1}$  is needed as part of the frequency averaging and the

second term  $4|AR(1)|^2$  adds the sum of intensities of the 4 layer reflected rays.

IF AUX > 0 GO TO 213 where the computation is completed. Otherwise set the value

ALOSS(JJ,J)=25. This is an assumed value.

GO TO 200 allows continuation of computations.

$$ALOSS(JJ,J) = -10 \log_{10} \frac{AUX}{4(\cos\theta/R)^2}$$

(355)

This completes the computations for the domain where Big Angle, Small Angle,

and basement reflected paths can all contribute. The 4 in the denominator

represents the sum of 4 unit intensities and  $(\cos\theta/R)^2$  is the inverse squared slant range factor.

CONTINUE

N=J-1

NA=J

DO 701 I=1,N

J=NA-I



IF J<NSAP GO TO 999 Stops computations for bottom angles too small for ray to travel from source or to receiver.

Statements from DR to last DT compute same quantities as in case for angles above critical (caustic) near the beginning of this subroutine, but for angles greater than NSAP.

ALOSS(JJ,J)=-10 log<sub>10</sub> DT gives loss for angles between SAP and TIR. For this case, total internal reflection occurs, no paths penetrate the layer, and it is assumed no losses occur in the sediment.

CONTINUE

GO TO 999 Stops the subroutine.

You will remember

IF J<NSAP the routine goes to 800.

N=J-1

NA=J

DO 801 I=1,N

J=NA-I

IF J<NTIR GO TO 999 Computations are done for angles between TIR and basement limiting ray angle, e.g. ray R1.b. shown in figure 2

COMPUTE BIG TRANSMISSION COEFFICIENT

ALOSS(JJ,J)=25 Loss value is assumed.

$ALPH2 = \alpha_2 = \frac{4\pi DF(JJ)\sin BA}{c_2}$  Uses Big Angle.

V=V\*BGI(J) gives the two-way transmission coefficient multiplied by the geometric amplitude as done before using Big Angle.

AUX3=|V|<sup>2</sup> gives intensity of two-way transmitted ray.

IF AUX3=0 GO TO 801 Skip rest of computation.

Otherwise compute

DR to last DT statement as done before in this subroutine.

$AUX2 = -4\pi\alpha_0 S \log_{10} e$  where S represents the effective Big Angle path in the sediment.

IF  $AUX2 * F2 < -40$  GO TO 801. causes this calculation to be skipped if

$-4\pi\alpha_0 S \log_{10} e < -40$ .

Otherwise compute

$$ALOSS(JJ, J) = -10 \left\{ -4\pi\alpha_0 S \log_{10} e + \log_{10} \left[ \frac{|V|^2 DT}{\left(\frac{\cos \Theta}{R}\right)^2} \right] \right\} \quad (356)$$
$$= -10 \log_{10} \left[ \frac{|V|^2 (DT) e^{-4\pi\alpha_0 S}}{\left(\frac{\cos \Theta}{R}\right)^2} \right]$$

Here only sediment refracted paths are considered--no layer reflection.

IF  $ALOSS(JJ, J) > 25$   $ALOSS(JJ, J) = 25$

This replaces the computed value when greater than 25 with the value 25 on the assumption that the greater value is unrealistic.

CONTINUE      Computations are made in steps of 1 degree for the allowable values.

RETURN

END      Stops SUBROUTINE LOSS(JJ)

### III. ANALYSIS OF DATA AND SELECTION OF VALUES FOR INPUT TO COMPUTER

Program BTLS has two input options. The choice of the option desired provides for the computation of either Geo-parameters or simulated bottom loss. In either case the environmental geometry is important and the following inputs are required.

1. T = thickness of the sediment (from the bottom of the water to the interface with the basement) is characterized, not by units of length, but by the two-way travel time for sound to travel from top of the sediment to the basement and return. This time should be entered in units of tenths of seconds. Two decimal places should be used (e.g., if the two-way travel time is, say, 1.7 seconds, it would be entered as 17.00.). The time may be obtained from sediment thickness charts or other source.

2. NNFILE = Arbitrary file number--a number which designates the geographical site of the measurements or predictions.

3. IOPT = input option, 0 for Geo-Parameters

1 for Inversion Parameters

IOPT=0 causes computation (and plotting) of simulated bottom loss.

IOPT=1 causes computation and printout of geo-parameters.

4. The data listed next is required for all computations, and it should not be controversial in nature.

ZB = water depth (of bottom below surface). Units are meters. Entry should contain two decimal places, e.g. ZB=4800.00.

ZS = depth of sound source below surface of water (Standard depth is 244 meters.) Units are meters. Entry should contain two decimal places, e.g. ZS = 244.00.

ZR = depth of receiver of sound below surface of water. Units are meters. Entry should contain two decimal places, e.g. ZR=305.00.

CS = Speed of sound in water at the depth ZR or ZS, whichever is smaller. Units are meters/second. Entry should contain two decimal places, e.g. CS=1507.00.

C1 = Speed of sound in water at bottom of water column. Units are meters/second. Entry should contain two decimal places, e.g. C1=1543.70.

#### GEOPHYSICAL PARAMETER COMPUTATION

For IOPT = 1 the INPUT INVERSION PARAMETERS required are listed below.

INPUT is format free. The following are required inputs.

- |           |          |
|-----------|----------|
| 1. DBLOSS | 8. THC   |
| 2. FREQ   | 9. RATIO |
| 3. THETA  | 10. G    |
| 4. ALOSSØ | 11. BETA |
| 5. ALOSSM | 12. GAM  |
| 6. FM     | 13. REF  |
| 7. TIR    |          |



The statements which follow are intended to be used for guidance in determining the rest of the necessary input data for computer runs of Program BTLS. Data, tables, and articles referred to are meant to be used as examples only. They may not represent true values for a given situation. As bottom loss work progresses, it is expected that much data will accumulate, and the techniques and "art" used in interpretation will become highly sophisticated. Therefore, it is essential to use all evidence at one's disposal, and take great care in choosing assigned or estimated values. Otherwise, large errors in output results should be expected. With this caveat in mind we proceed to a discussion of ways and means to arrive at input data.

For the measurement location, the bulk sediment type is to be obtained from measured core data, core data summaries, or other source. The type of sediment must be known in order to choose properly some assigned values.

The quantities DBLOSS, FREQ, and THETA are used to compute  $ALPH\theta$ , the logarithmic attenuation coefficient of the sediment in dB/m/kHz.

DBLOSS is a value found by inspection of a graph (or possibly a table of data) of measured bottom loss as a function of apparent grazing angle. Consider Figure 18 as an example. Look on the curve for the frequency 400 Hz. Find a reasonably smooth portion of the curve which seems to be as nearly linear as possible. Read the graph and determine the bottom loss in DB and the apparent bottom grazing angle for a point on the smooth linear portion of the curve. For example DBLOSS = 3.5 dB, FREQ = 400 Hz, THETA = 20 degrees. Entry should contain two decimal places, e.g. DBLOSS = 3.50.

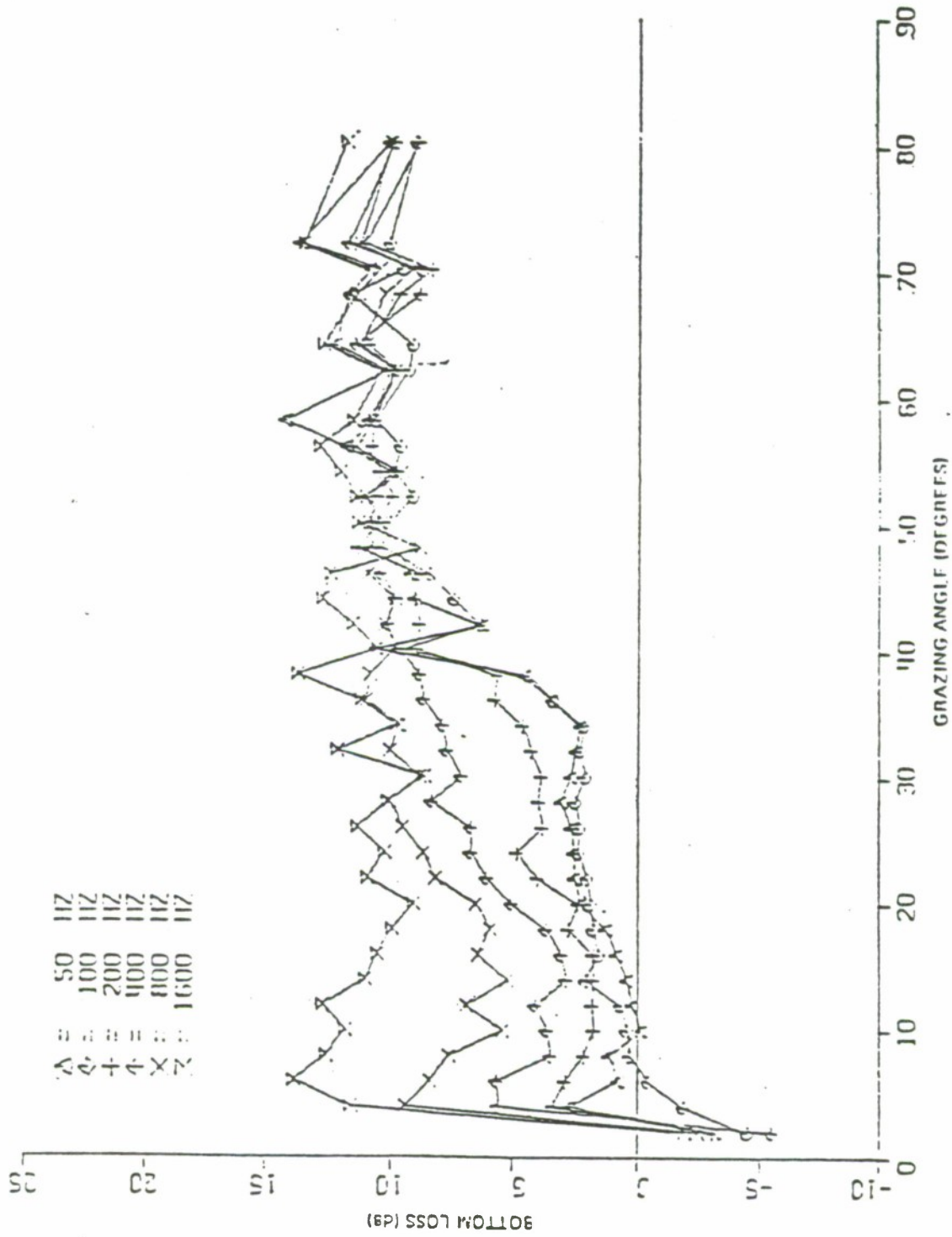


Figure 18. Bottom loss versus grazing angle measured in six one-octave bands at indicated center frequencies: zero high-angle frequency dependence.

For other examples consider Figure 19 where  $DBLOSS = 4\text{dB}$ ,  $FREQ = 400\text{ Hz}$ ,  $THETA = 20^\circ$  while Figure 20 indicates  $DBLOSS = 8.5\text{ dB}$ ,  $FREQ = 400\text{ Hz}$ ,  $THETA = 20^\circ$ . Note that usually one should choose mid-frequencies and modest grazing angles to obtain values of  $DBLOSS$ ,  $FREQ$ , and  $THETA$ .

$ALOSS\emptyset$ ,  $ALOSSM$ , and  $FM$  are used to compute the density of the layer above the sediment,  $\rho_2 = RH2$ , the density of the sediment,  $\rho_3 = RH3$ , and the thickness  $D$  of the layer. To find these input quantities look at the bottom loss curves. Look at the portions of the curves for large angles. Find the frequency at which the loss is smallest. This frequency is the value  $FM$ . The units to be used for this quantity are Hertz (Hz). Now read the minimum value of bottom loss for the curve just selected. This minimum value of bottom loss is  $ALOSSM$  in units of dB and usually occurs at relatively high frequency. This quantity is characteristic of the thin layer and of frequencies greater than 300 to 400 Hz, therefore data for frequencies lower than 300-400 Hz should not be used here. The value of  $ALOSS\emptyset$  is the amount of bottom loss where the curve has a maximum at low frequency (say, less than 300-400 Hz). These entries should all contain two decimal places, e.g.  $ALOSS\emptyset = 9.00$ ,  $ALOSSM = 7.00$ ,  $FM = 1600.00$ .

The angle of total internal reflection,  $TIR$ , is the largest grazing angle where no sound energy penetrates into the layer or sediment. All the sound is reflected from the bottom for bottom grazing angles less than this angle. This phenomenon can occur for sediments (or the top layer) in which the speed of sound is greater than the speed of sound at the bottom of the water column. For the angle  $TIR$  and smaller angles there is no bottom loss.

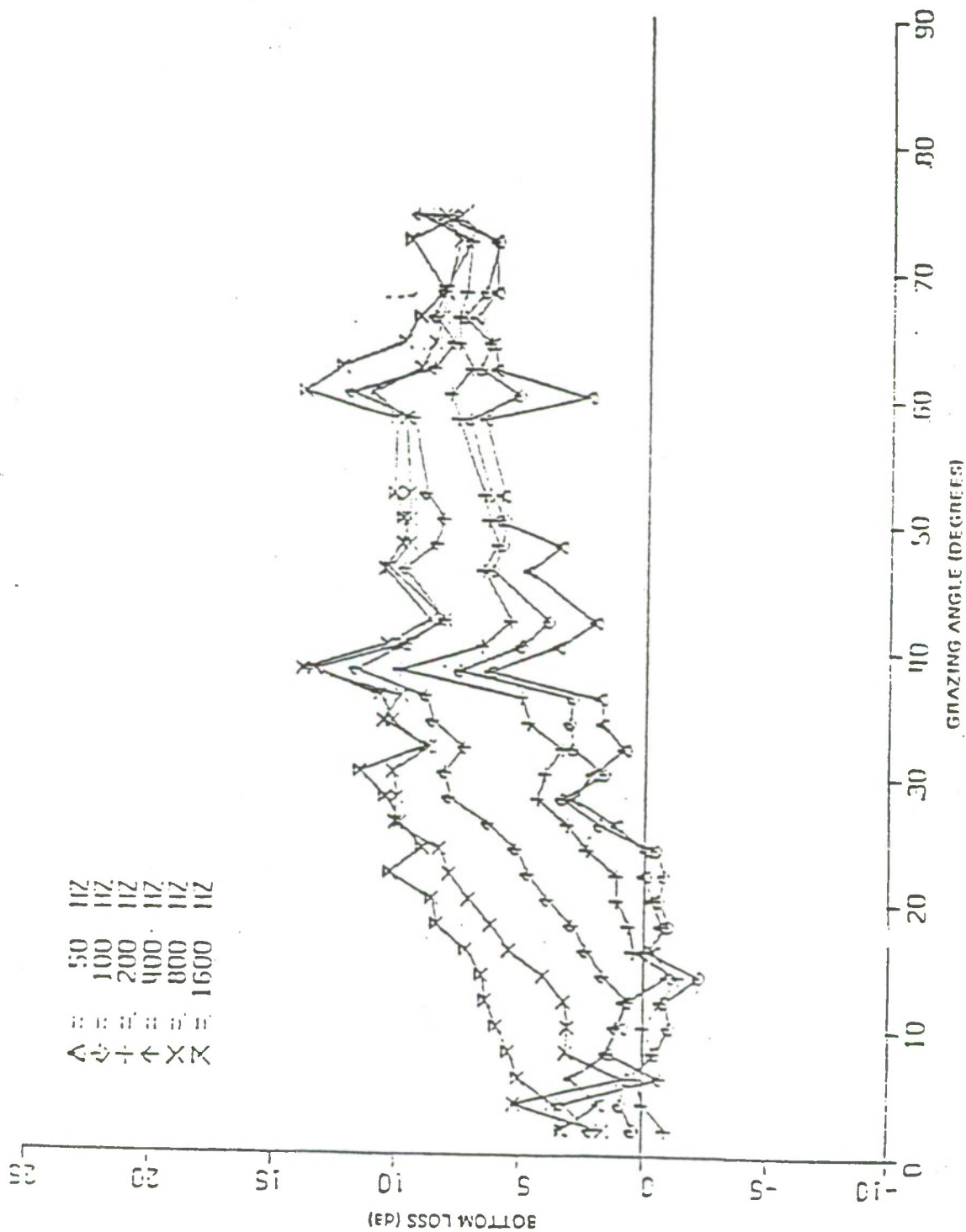


Figure 19. Bottom loss versus grazing angle measured in six one-octave bands at indicated center frequencies: positive high-angle frequency dependence.



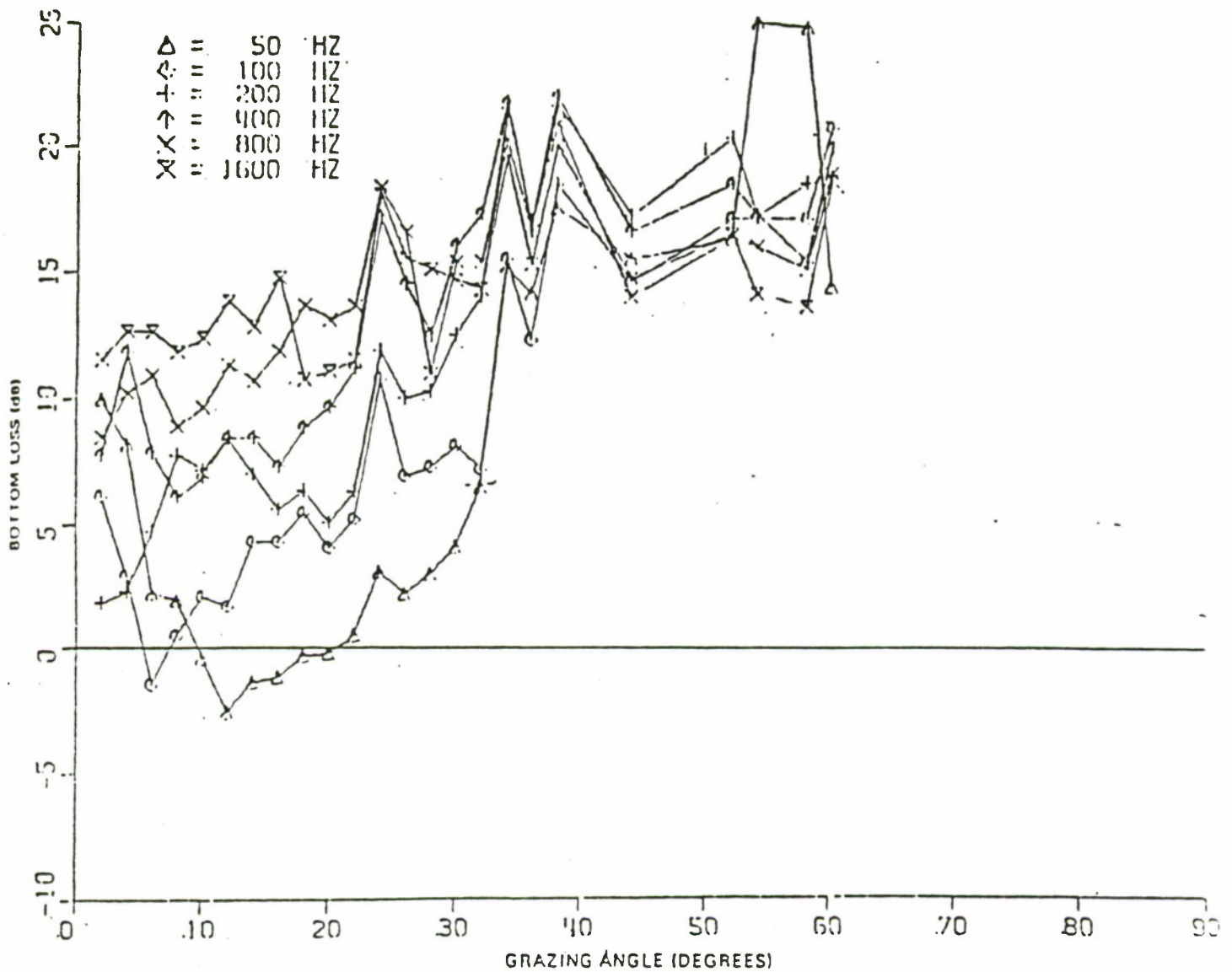


Figure 20. Bottom loss versus grazing angle measured in six one-octave bands at indicated center frequencies: negative high-angle frequency dependence.

After Spofford et al. (1982)

Consequently, you should inspect the bottom loss curves and find the greatest angle for which there is a zero value of bottom loss. This angle is TIR and the units are degrees. Entry should have two decimal places, e.g. TIR = 10.00.

The caustic angle, THC, is the apparent bottom grazing angle, at which there is a marked increase in bottom loss. For example, in Figure 18 the caustic angle  $\text{THC} = 40^\circ$  as indicated by spikes in the curves. Notice Figure 19; no caustic effect can be found here. The sediments are not thick enough to allow the caustic to form. The basement grazing ray appears to correspond to the bottom grazing angle of about 25 degrees. This figure is discussed further under High Angle Losses, Type 2. In Figure 20 the caustic angle is at  $34^\circ$ . Use degrees as the proper units for THC. This angle is interpreted as the boundary separating strong sediment refracting paths from weak reflected paths. Entry should have two decimal places, e.g. THC = 39.00.

The quantity RATIO is the value of the speed of sound in the top layer of the sediment, C2, divided by the speed of sound in the water at the bottom of the water column. It is computed by use of Snell's law from the angle TIR. Alternately, if desired, it can be an assigned value. It is a number without units. Hamilton's value of sound-speed ratio by sediment type from Table 1, reproduced here from Spofford et al. (1982), has been used directly and given satisfactory results in some cases. In some instances it should be adjusted to account for unusually low or high-speed bottoms which manifest themselves in the data by either a finite loss at zero or minimal grazing angle, or zero loss at a finite grazing angle, respectively. The entry should have four decimal places, e.g. RATIO = 1.0040.

Table I. Sound Speed profile parameters from Hamilton<sup>10</sup>  
by sediment type and corresponding values of  $\beta$  for  $c(z)$   
given by Equation (15). (units - km, sec)

Sediment Type	$c_o$	$\beta_o$	$\gamma$	$\delta$	Values at 500 m			Fitted $\beta$	
					$c$	$g$	$\beta_c$	$\beta_g$	
Turbidites	1.511	1.304	-0.741	0.257	2.010	0.756	-0.46	-0.56	
Siliceous	1.509	0.869	-0.267	0	1.877	0.602	-0.33	-0.47	
Calcareous	1.559	1.713	-0.374	0	2.322	1.339	0.99	0.73	

Spofford, Greene, and Hersey -  
J. Acoust. Soc. Am.

After Spofford et al. (1982)

The gradient of the speed of sound in the sediment at the top of the sediment is designated G. This quantity is computed from input data including the apparent caustic grazing angle, THC, especially. If desired, an assigned value can be used for input data. Units are 1/second. Hamilton's tabulated values are suggested as a source of numerical values when it is desired to assign a value. Table 1 may be used as a source of possible values with the caution that these values are to be considered as examples only. Entry should have two decimal places, e.g.  $G = 1.79$ .

The parameter  $BETA=B$  controls the rate of decrease of the sound speed gradient in the sediment with increasing depth and increasing sound speed. It controls the shape of the sound speed profile. Its values lie between -1 and + infinity. This parameter is a pure number with no units. The value of B must be assigned. Some typical values of B are given in Table 1. As illustrated in the table, the value of B is based upon the type of sediment at the site under consideration. Values given in Table 1 are typical values only and may not be characteristic of a particular site (NNFILE number). Entry should show a sign and two decimal places, e.g.  $BET=-.50$ .

The quantity  $GAM=\gamma$  is the gradient of the logarithmic attenuation coefficient of the sediment and has units  $dB/m^2/kHz$ . The value of this quantity must be assigned. The value of GAM ranges from 0 to 0.00040 and, as mentioned in "Documentation of Bottom Loss Upgrade Parameters," increments may be typically 0.00005. Roughly the value  $GAM = 0.00005$  corresponds to terrigenous abyssal plain sediments,  $GAM = 0.00010$  to terrigenous continental rise sediments, and  $GAM = 0.00020$  to calcareous sediments. The non-linear loss at higher angles and lower frequencies may help in estimating GAM. The entry should show 5 decimal places, e.g.  $GAM = 0.00010$ .



The basement reflection coefficient REF is a pure number used to represent the sound pressure reflection coefficient for sound penetrating the sediment, reflecting from the basement, and returning through the sediment to the water. The value must be assigned. This is a pure number with no units, and its value is in the range from 0 to 1. Basement reflected paths may make important contributions to the sound level after a bottom interaction occurs. Sometimes this effect is observable in bottom loss curves. For example, a look at Figure 19 shows a rise in the curves at a bottom grazing angle of 28°. This has been interpreted as the effect of reflection of the sound from the basement, the onset of basement reflection taking place at 28°. Basement reflection coefficients, REF, of 0.4 to 0.5 independent of frequency and grazing angle appear to be quite common. The entry should contain two decimal places, e.g. REF = 0.50.

High angle losses are discussed by Spofford et al. (1982) as follows:

D. High Angle Losses

*At the higher angles the bottom-loss data show several characteristic patterns. Very little significant angle dependence is apparent; however, four types of frequency dependence have been identified:*

Type 1. Zero (0) Frequency Dependence

*This is the simplest behavior and represents the frequency and angle-independent loss characteristic of a two-fluid interface. Figure 18 is a good example of this type where the loss of approximately 10 dB corresponds to an impedance of 3.2 or a sediment density of 2.0 g/cm<sup>3</sup>, characteristic of sandy-silt found on continental terraces.*

Type 2. Positive (+) Frequency Dependence

*When the sediments are not so thick, at the high angles the interface-reflected path is augmented by a basement-reflected path which can carry significant energy, especially at the lower frequencies where volume attenuation in the sediment is diminished. Figure 19 illustrates such a case. The sediments are not thick enough to allow the caustic to form. In fact the basement grazing ray appears to correspond to the bottom-grazing angle of about 25*

degrees consistent with the known sediment thickness at this location of approximately 90 meters and the gradient appropriate to this type of calcareous sediment of  $1.7 \text{ sec}^{-1}$ . The higher frequency losses, dominated by the interface-reflected wave, tend to cluster around 10 dB. As the frequency decreases, the amplitude of the basement-reflected path increases until the two paths have comparable amplitude at 200 Hz (thereby reducing the loss by 3 dB). At 50 and 100 Hz the basement return dominates and attenuation effects are nearly negligible. Basement reflection coefficients of 6-8 dB corresponding to  $REF = 0.4-0.5$  independent of frequency and grazing angle appear to be quite common.

### Type 3. Negative (-) Frequency Dependence

A third type of frequency dependence at high angles is illustrated in Figure 20. Here the high frequencies show less loss than the low frequencies. This appears to be modelable as a thin high-impedance layer at the top of the sediment. The shorter wavelengths respond to this impedance while longer wavelengths tend to "see" through the layer, responding more strongly to the lower impedance characteristic of the bulk of the sediment as the frequency decreases. In this case, it would appear that the thin layer has an effective impedance ratio of 1.50, whereas the bulk of the sediments has a near-surface ratio of 1.29. The higher impedance is characteristic of sandy silt, whereas the bulk of the sediment might be clayey silt.

### Type 4. Reversing ( $\pm$ ) Frequency Dependence

A fourth type of behavior is occasionally observed when the thin-layer (Type 3) effect appears to peak at a particular frequency. In Figure 21 the loss decreases at high angles until 200 Hz, where it reaches a minimum and then increases. This strongly suggests a high-impedance layer (or set of layers) which acoustically resonates at 200 Hz. If, in fact, this is a single layer it would then have to be about 2 meters thick with a well defined lower interface with the sediment.

## RESULTS OF GEO-PARAMETER COMPUTATION

The inversion computation yields results as follows:

$$RATIO = \frac{C_2}{C_1}$$

$RH_2$  = density of top layer of sediment in  $\text{gram/cm}^3$ .

$RH_3$  = density of sediment below the layer in  $\text{gram/cm}^3$ .

$D$  = thickness of the top layer in meters.

$G$  = sound speed gradient at the top of the sediment in units  $\text{sec}^{-1}$ .

$B$  = sound speed profile parameter, no units.

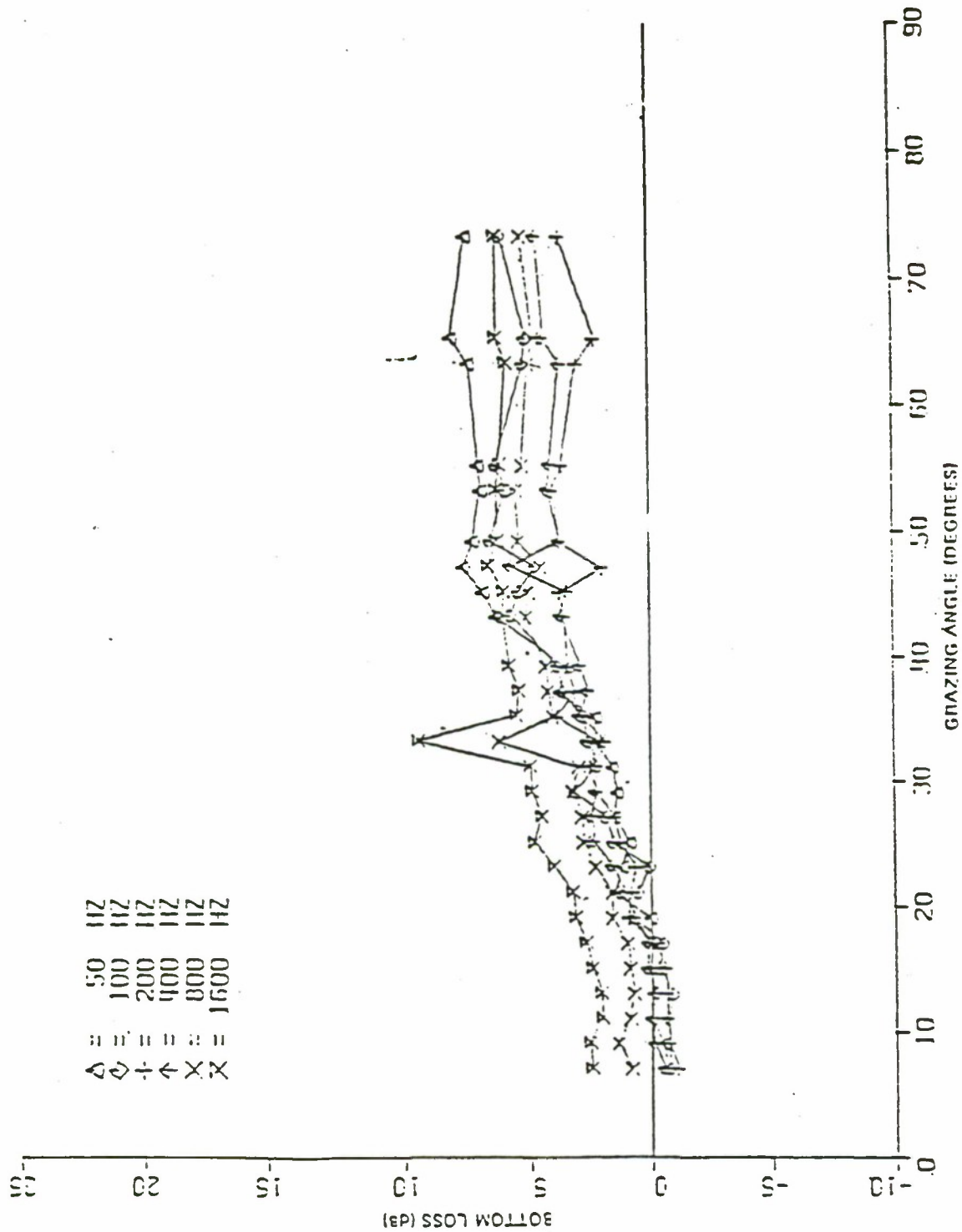


Figure 21. Bottom loss versus grazing angle measured in six one-octave bands at indicated center frequencies: reversing high-angle frequency dependence.

After Spofford et al. (1982)

ALPHØ = logarithmic sound attenuation coefficient for sound in sediment,  
units DB/m/kHz.

GAM = attenuation coefficient gradient in units of dB/m<sup>2</sup>/kHz.

BZ = depth of the sediment in meters.

REF = basement reflection coefficient, no units.

### BOTTOM LOSS COMPUTATION

If bottom loss is the desired result, use input option statement.

IOPT = 0.

The required input data is listed below.

This example illustrates the number of decimal places needed for each entry:

- |                   |                  |
|-------------------|------------------|
| 1. RATIO = 1.0040 | 6. D = .24       |
| 2. G = 1.79       | 7. ALPHØ = .029  |
| 3. BETA = -.50    | 8. GAM = .00010  |
| 4. RH2 = 2.33     | 9. REF = .50     |
| 5. RH3 = 2.09     | 10. BZ = 1067.78 |

These quantities mentioned before have the same definitions given before.

The computation yields values of bottom loss in dB in steps of 1 degree for all applicable apparent bottom grazing angles from 0 to 90°. Computations are done for the following frequencies (in Hz): 50, 100, 200, 400, 800, and 1600, or others as specified. Frequencies mentioned are the frequencies of the centers of bands one-octave wide, and the computed bottom loss is a frequency-averaged value for the one octave bandwidth. The results are plotted in graphical form.



For runs involving a basement reflection, if 90 degrees is reached on the loss plot, the loss value increases to the value one would have if no basement return were present. This may be helpful to the user in evaluating the effects of basement reflection and in adjusting the value of the basement reflection coefficient REF.

Computed bottom loss values of 25dB should be treated suspiciously because they may be the result of computations which result in loss values of greater than 25dB. These are thought to be physically unrealistic so are set arbitrarily at 25dB by the computer. See statement in Subroutine LOSS:

ALOSS(JJ,I)=25.

See also similar statements between 212 and 213 and between 800 and 801 of Subroutine LOSS.

#### IV. CONCLUSIONS

The computer program directs computations of geo-acoustic ocean bottom parameters and simulated bottom loss, generally in accordance with the criteria outlined in the description of the model of Spofford et al.(1982). The program has been implemented on HP 1000 computers inhouse at the Naval Oceanographic Office and aboard ship at sea. At present, new bottom loss data is being acquired by experiments at sea, and results are being computed by use of PROGRAM BTLS. Some initial problems with use of the program have been overcome, and use and evaluation are continuing. Some problems associated with the program are discussed in the section containing recommendations.

## V. RECOMMENDATIONS

It is recommended that changes be made to the program as follows:

In SUBROUTINE GEOPHYS change line  $D=C1/FM/4$  to read  $D=C2/FM/4$ .

Change line  $AUX=4*D*PI*FREQ/C1*SIN(THETA)$  to read  $AUX=4*D*PI*FREQ/C2*SIN(THETA)$ .

These changes change the speed of sound in the layer at the top of the sediment to the correct value  $C2$ . Change  $AUX=AUX/T$  to read  $AUX=AUX/T**2$  in order to compute the square of the two-way layer transmission coefficient.

Once these changes are carried out, the program should be run again with data used for previous computations done before making these changes. A careful evaluation of the old and new results should be made to determine the effects of these changes.

The program computations are based upon an assumed bandwidth of 1 octave. This is important in the calculation of simulated bottom loss. The actual bandwidth used in processing measured signals to provide input data for computing geo-parameters does not seem to be important, because only the band center frequency is designated, and the bandwidth does not enter into the calculations. Nevertheless, when comparing simulated bottom loss plots with actual measured bottom loss data, the bandwidth used for the simulation should be the same as the bandwidth used to obtain the measured data. It seems that all recent measured data is processed with a 1/3 octave bandwidth. Therefore, discrepancies should be expected in a comparison of simulated bottom loss with 1/3 octave bandwidth measured loss. It is recommended that the same bandwidth be used in computing simulated bottom loss and for processing measurements of bottom loss.

## VI. REFERENCES

SPOFFORD, C. W.; GREENE, R. R.; and HERSEY, J. B., "The Estimation of Geo-Acoustic Ocean Sediment Parameters from Measured Bottom-Loss Data," (1982) to be published in the Journal of the Acoustical Society of America.

Documentation of Bottom Loss Upgrade Parameters, anon. (1982).

BREKHOVSKHIK, L.M., Waves in Layered Media, 2nd Edition (Academic Press, New York 1980).



APPENDIX A

PROGRAM BTLS

48TL10 T=00003 IS ON CR00032 USING 00371 BLKS R=0000

```

0001 FTH4X,L
0002 PROGRAM BTL10
0003 C
0004 C THIS PROGRAM SIMULATES MEASURED BOTTOM LOSS DATA
0005 C INCLUDING MEASUREMENT ARTIFACTS
0006 C
0007 C BLANK COMMON CONTAINS GEORACOUSTIC PARAMETERS
0008 C
0009 C
0010 COMMON ZB,ZR,ZS,C1,C2,C3,RN1,RH2,RH3,G,D,ALPN0,CS,BZ,REF,HEAD(20)
0011 COMMON /ALPH/GAM
0012 COMMON /T/T
0013 C
0014 C COMMON BLOCK AL CONTAINS THE SIX FREQUENCIES DEFINED
0015 C IN THE FOLLOWING DATA STATEMENT IN F, AND CORRESPONDING
0016 C BOTTOM LOSS FOR THE SIX FREQUENCIES AND 90 ANGLES IN
0017 C ALOSS. THE VALUE IN ALOSS ARE CALCULATED IN SUBROUTINE LOSS.
0018 C NOTE 1
0019 C ALL VALUES OF ALOSS ARE RETAINED, WHICH IS
0020 C NOT NECESSARY IN THIS VERSION OF THE PROGRAM.
0021 C
0022 COMMON/AL/F(6),ALOSS(6,90)
0023 DIMENSION BRAY(600)
0024 EQUIVALENCE (BRAY(1),F(1)),(BRAY(7),ALOSS(1,1))
0025 C
0026 C LOOP 500 READS A SET OF INPUT DATA AND GENERATES A SET
0027 C OF BOTTOM LOSS DATA ON EACH PASS UP TO A MAXIMUM
0028 C OF 10 CASES
0029 C
0030 C
0031 C SUBROUTINE LOS2 CALCULATES ALL FREQUENCY INDEPENDENT
0032 C INTERMEDIATE VARIABLES
0033 C
0034 CALL LOS2
0035 IF(T.EQ.999) GO TO 999
0036 C
0037 C LOOP 41 CALCULATES BOTTOM LOSS AT A PARTICULAR
0038 C FREQUENCY IN SUBROUTINE LOSS AND PRINTS IT
0039 C OUT ON EACH PASS.
0040 C
0041 DO 41 J=1,6
0042 CALL LOSS(J)
0043 WRITE(6,2)(ALOSS(J,I),I=1,90)
0044 2 FORMAT(1X,8F8.2)
0045 41 CONTINUE
0046 CALL EXEC(14,2,BRAY,1200)
0047 WRITE(1,69)
0048 69 FORMAT(' NORMAL TERMINATION -- BOTTOM LOSS MODEL ')
0049 STOP
0050 END
0051 SUBROUTINE LOS2
0052 COMMON ZB,ZR,ZS,C1,C2,C3,PH1,RH2,RH3,G,D,ALPN0,CS,BZ,REF,HEAD(20)
0053 COMMON /DATA/ LZEP0,LZEP0,FZEP0,L70,F70,TH70,L71,F71,DBLOSS,FREQ,THETA,
0054 1 ALOSS0,ALOSSM,FN,TIR,THC,THPC,TNIB,BETA
0055 C
0056 COMMON /ALPH/GAM
0057 COMMON/T/T
0058 REAL LZEP0,L70,L71

```

```

0059 DATA PI/3.141592655/
0060 RN1=1
0061 C
0062 C
0063 C
0064 C
0065 C
0066 C
0067 C
0068 C
0069 C
0070 C
0071 C
0072 701
0073 *
0074 *
0075 *
0076 READ(1,*) NNFILE,IOPT
0077 IF(IOPT.EQ.2) GO TO 999
0078 WRITE(1,702)
0079 FORMAT(' ENTER THE TWO-WAY TRAVEL TIME THICKNESS IN 10THS OF SECOND
0080 *DS: ')
0081 READ(1,*) T
0082 C
0083 C
0084 C
0085 C
0086 C
0087 C
0088 C
0089 C
0090 705
0091 READ(1,*) Z8
0092 WRITE(1,706)
0093 FORMAT(' ENTER SOURCE DEPTH AND RECEIVER DEPTH: ')
0094 READ(1,*) ZS,ZR
0095 WRITE(1,707)
0096 FORMAT(' ENTER SOUND SPEED AT SOURCE OR RECEIVER - WHICHEVER IS SH
0097 *ALLOWED: ')
0098 READ(1,*) CS
0099 WRITE(1,708)
0100 FORMAT(' ENTER SOUND SPEED AT THE BOTTOM OF THE WATER: ')
0101 READ(1,*) C1
0102 C
0103 C
0104 C
0105 C
0106 C
0107 C
0108 C
0109 C
0110 C
0111 709
0112 *
0113 *
0114 *
0115 READ(1,*) DBLOSS,FREQ,THETA
0116 WRITE(1,710)
0117 FORMAT(' ENTER LOW FREQ LOSS LEVEL AT HIGH ANGLES: ',
0118 * THE MINIMUM LOSS LEVEL AT HIGH ANGLES: ',

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0179 C      OPTIONAL BRANCH TO INPUT GEO-PARAMETERS DIRECTLY
0180 C
0181 500 CONTINUE
0182 WRITE(1,715)
0183 FORMAT(' ENTER RATIO OF SPEED IN SEDIMENT TO SPEED AT BOTTOM OF WA
0184 *TER:')
0185 READ(1,*) RATIO
0186 WRITE(1,716)
0187 FORMAT(' ENTER GRADIENT AT TOP OF SEDIMENT AND CANONICAL CURVE TYP
0188 *E:')
0189 READ(1,*) G,BETA
0190 WRITE(1,717)
0191 FORMAT(' ENTER THIN LAYER DENSITY, SEDIMENT DENSITY AND THIN LAYER
0192 * TKNICKNESS IN METERS:')
0193 READ(1,*) RN2,RH3,D
0194 WRITE(1,718)
0195 FORMAT(' ENTER SURFACE ATTENUATION IN DB/M/KHZ:')
0196 READ(1,*) ALPH0
0197 WRITE(1,719)
0198 FORMAT(' ENTER ATTENUATION PROFILE GRADIENT AND BASEMENT REFLECTIO
0199 *N COEFFICIENT IN PRESSURE:')
0200 READ(1,*) GAM,REF
0201 C
0202 C2=C1*RATIO
0203 C3=C2
0204 C
0205 C CALL A SUBROUTINE WHICH CALCULATES AND PRINTS VARIOUS
0206 C CRITICAL ANGLES CHARACTERISTIC OF THE MEASUREMENT
0207 C GEOMETRY
0208 C
0209 499 CALL CANGLE
0210 C
0211 C PRINT GEO-PARAMETERS
0212 C
0213 WRITE(6,145)
0214 FORMAT(//, ' GEO-PARAMETERS ',//)
0215 WRITE(6,146) RATIO,RN2,RN3,D,G,BETA,ALPH0,GAM,BZ,REF
0216 FORMAT(' RAT=',F8.4,/, ' RN2=',F8.2, ' RN3=',F8.2,/,
0217 1' D =',F8.2,/, ' G =',F8.2, ' BET=',F8.2,/,
0218 2' AL0=',F9.3, ' GAM=',F11.5,/, ' BZ =',F8.2, ' REF=',F8.2,//)
0219 C
0220 C CALL ROUTINES FOR FREQUENCY-INDEPENDENT INTERMEDIATE
0221 C VARIABLE
0222 C
0223 CALL REFL
0224 CALL REFR
0225 CALL BASE
0226 C
0227 999 RETURN
0228 END
0229 SUBROUTINE GEOPY
0230 COMMON ZB,ZR,ZS,C1,C2,C3,RN1,RN2,RN3,G,D,ALPH0,CS,BZ,RE,NEAD(20)
0231 COMMON/DATE/LZERO,FZERO,L70,F70,TN70,L71,F71,DBLOSS,
0232 IFREQ,THETA,ALOSS0,ALOSSM,FM,TIR,TNC,TNRC,TN1R,BETA
0233 COMMON /ALPH/GAM
0234 PEAL LZERO,L70,L71
0235 DATA PI/3.141592655/
0236 COMPUTE DENSITIES RH2,RH3
0237 Z1=C1*RH1
0238 D=C1/PM/4

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0239 R=EXP(-ALOG(10.)*ALOSS0/20)
0240 Z3=(1+R)/(1-R)*Z1
0241 R=EXP(-ALOG(10.)*ALOSSM/20)
0242 Z2=(1+R)/(1-R)*Z1*Z3
0243 Z2=SQRT(Z2)
0244 SPRAT=C3/C1
0245 RN2=Z2/C2
0246 RN3=Z3/C3
0247
0248 COMPUTE DISSIPATION CONSTANT ALPHA0
0249 TNETA=ACOS(C2/C1*COS(THETA))
0250 BS=SIN(TNETA)
0251 BC=COS(THETA)
0252 V21=(Z2-Z1)/(Z2+Z1)
0253 V32=(Z3-Z2)/(Z3+Z2)
0254 V21=(Z2-Z1)/(Z2+Z1)
0255 AUX=4*D*PI*FREQ/C1*SIN(THETA)
0256 V=CABS(C(V21+V32*CMPLX(COS(AUX),SIN(AUX))))
0257 ICMLX(COS(AUX),SIN(AUX)))
0258 T=CABS(1/(1+V21*V32*CMPLX(COS(AUX),SIN(AUX))))**2
0259 I*16*Z1*Z3*(Z2/(Z1+Z2)/(Z2+Z3))**2
0260 AUX=10.*(C-DBLOSS/10.)*V**2
0261 AUX=AUX/T
0262 ALS=-ALOG10(AUX)*10
0263 FK=FREQ/1000
0264 SIG=G*(1+BETA)*C2
0265 AMU=(C2*(1+BETA))***2
0266 ANU=BETA*C2
0267 ALPH0=ALS/FK-2*C2/G/(1+BETA)/BC*
0268 1/GAM+C2*2/2/SIG/BC**3*(BS-BS**3/3)+
0269 2*(BETA*GAM*C2**2+2*GAM*AMU*C2)/4/SIG/BC**2*
0270 3*(TNETA+BS*BC)*
0271 4*(GAM*(AMU**2-AMU)+2*BETA*GAM*AMU*C2)/2/SIG/BC*BS*
0272 5BETA*GAM*(AMU**2-AMU)/2/SIG*THETA)
0273 ALPH0=ALPH0/(BS/BC+BETA*THETA)*G*(1+BETA)*BC/2/C2
0274 RETURN
0275 END
0276 SUBROUTINE CANGLE
0277
0278 COMMON ZB,ZR,ZS,C1,C2,C3,RN1,RN2,RN3,G,D,ALPH0,CS,BZ,RE,HEAD(20)
0279 COMMON /ALPH/GAM
0280 COMMON /T/T
0281
0282 COMMON /DATA/ LZERO,FZERO,L70,F70,TN70,L71,F71,DBLOSS,FREQ,
0283 1TNETA,ALOSS0,ALOSSM,FH,TIR,TNC,THRC,TH1B,BETA
0284
0285 REAL LZERO,L70,L71
0286
0287 DATA PI/3.14159264/
0288
0289 DI=2.*ZB-ZR-ZS
0290
0291 CALCULATE SEDIMENT THICKNESS
0292
0293 B=8BETA
0294 C2P=2000
0295 A=C2*(G*(1+B)*T+1.+B*ALOG(C2))
0296 CZ=C2P*(A-C2P-B*C2*ALOG(C2P))/(1.+B*C2/C2P)
0297 IF(ABS(C2-C2P),L.T.,.01) GO TO 70
0298 C2P=CZ
0299 GO TO 60
0300
0301 R7=(C2+B*C2)**2-C2**2*(1+B)***2)/(C2+G*(1+B)*C2)
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0339 C                                     MAY82
0340 C                                     MAY82
0341 C                                     MAY82
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0343 C                                     MAY82
0344 1                                     MAY82
0345 11                                    MAY82
0346                                     MAY82
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0349                                     MAY82
0350 999                                 MAY82
0351                                     MAY82
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0354                                     MAY82
0355                                     MAY82
0356                                     MAY82
0357 C                                     MAY82
0358                                     MAY82

      COMPUTE REFINED CRITICAL ANGLE

      THRC=PI/4
      CALL TOTCI

      COMPUTE CRITICAL RAY DEPTH CRD

      CAUX=C1/COS<THRC>
      CRD=(<CAUX+BETA*C3>)*2-<C3*<(1+BETA)>)*2)/2/G/<(1+BETA)>/C3

      CALCULATE VELOCITY, VELOCITY GRADIENT, AND ATTENUATION
      CONSTANT AT DEPTH OF 500 METERS

      BSPD=SQRT<2*C*<(1+BETA)>*C3+500+C3**2*<(1+BETA)>)*2>-8*BETA*C3
      BGRAD=C*<(1+BETA)>/<BSPD/C3+BETA>
      AL80T=ALPH0+GAM*500

      COMPUTE TWO WAY TRAVEL TIME IN SECONDS

      TWTT=2*T
      SPRAT=C2/C1

      COMPUTE BASEMENT CRITICAL ANGLES TH18,TH38

      C8=SQRT<2*C*<(1+BETA)>*C3+82+C3**2*<(1+BETA)>)*2>-8*BETA*C3
      TH18=ACOS<C1/C8>
      TH38=ACOS<C3/C8>
      R=D1/TAN<TH18>+2*C3*TAN<TH38>/G*<BETA/<(1+BETA)>)*
      1<(1+<1+TH3B/SIN<TH38>/COS<TH38>)/2/BETA>

      COMPUTE SMALLEST APPARENT ANGLE FOR BASEMENT REFLECTION

      TH8=ATAN<D1/R>

      CHANGE RADIAN TO DEGREES

      TH8=TH8*180/PI
      A=TIR*180/PI
      A1=THC*180/PI
      A2=THRC*180/PI
      A3=TH18*180/PI

      PRINT OUT CRITICAL ANGLES

      WRITE<6,1>
      FORMAT<1X,/,/, " CRITICAL ANGLES",/
      WRITE<6,11>A,SPRAT,A1,A2,TH8,A3,TWTT,82,CRD,BGRAD,BSPD,AL80T,GAM
      FORMAT<" TIR =",F8.2," RAT =",F8.4," THC =",F8.2," THRC =",F8.2,
      1/, " TH8 =",F8.2," THR8 =",F8.2,
      2/, " TWTT =",F8.2," 82 =",F8.2," CRD =",F8.2,/,
      3- G500 =",F8.2," C500 =",F8.2," A500 =",F9.3," GAM =",F11.5>
      RETURN
      END

      SUBROUTINE TOTCI
      COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,ALPH0,CS,AZ,REF,HEAD<20>
      COMMON/DATA/LZERO,FZERO,L70,TH70,L71,F71,DBLOSS,
      IFREQ,THETA,ALOSS0,ALOSSM,FM,TIR,THC,THRC,TH18,BETA
      REAL LZERO,L70,L71
      CHECK THAT C3 LESS THAN C2
      IF<C3.LE.C2>GO TO 10

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0359      WRITE(1,11)
0360      11 FORMAT(' C3 MUST BE LESS THAN OR EQUAL TO C2')
0361      STOP
0362      10 P1=3.141592654
0363      C COMPUTE TIR=ANGLE OF TOTAL INTERNAL REFLECTION
0364      TIR=0
0365      IF(C2.LE.C1)GO TO 100
0366      TIR=ACOS(C1/C2)
0367      100 CONTINUE
0368      C COMPUTE TNC=CRITICAL ANGLE (CAUSTIC)
0369      P1=3.141592654
0370      P12=PI/2
0371      DELT=PI/180
0372      D1=2*Z8-ZR-ZS
0373      D2=2*C3/G
0374      D2=D2*BETA/(1+BETA)
0375      FAC=C3/C1
0376      TN3=ACOS(FAC*COS(TNRC))
0377      R=D1/TAN(THRC)+D2*TAN(TN3)*(1+(1+TN3/SIN(TH3))/COS(TN3))/2/BETA)
0378      C MINIMIZE EXPRESSION FOR RANGE BY CONJUGATE DIRECTIONS
0379      DO 200 I=1,1000
0380      AUX=THRC+DELT
0381      IF(AUX.GE.PI2)GO TO 500
0382      IF(AUX.LE.TIR)GO TO 500
0383      THRC=AUX
0384      TN3=ACOS(FAC*COS(TNRC))
0385      RAUX=D1/TAN(THRC)+D2*TAN(TN3)*(1+(1+TH3/SIN(TH3))/COS(TH3))/2/BETA)
0386      IF(RAUX.GT.R)GO TO 500
0387      R=RAUX
0388      GO TO 200
0389      500 R=RAUX
0390      DELT=-DELT/3
0391      IF(ABS(DELT).LE.1.E-6) GO TO 999
0392      200 CONTINUE
0393      WRITE(1,1)
0394      1 FORMAT(' CRITICAL ANGLE FAILED TO CONVERGE')
0395      STOP
0396      C BOTTOM ANGLE OF REFRACTED RAY AT CRITICAL ANGLE
0397      THC=ATAN(D1/R)
0398      C8=SQRT(2*G*(1+BETA)*C3*B2+(C3*(1+BETA))*2)-BETA*C3
0399      TH18=ACOS(C1/CB)
0400      RETURN
0401      END
0402      SUBROUTINE REFL
0403      COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,ALPH0,CS,BZ,REF,NEAD(20)
0404      COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71,F71,DBLOSS,
0405      IFREQ,THETA,ALOSS0,ALOSSM,FM,T1R,THC,THRC,TH18,BETA
0406      REAL LZERO,L70,L71
0407      COMMON /R/NSAP,RV21,RV32,RSIN2,RDTS,RDTR,RT,RGI
0408      DIMENSION RV21(90),RV32(90),RSIN2(90),RDTS(90),RDTR(90),RT(90),
0409      1PG1(90)
0410      C*****
0411      C RETURNS IN COMMON
0412      C NSAP=NSAP=SMALLEST ANGLE(DEG) TO REACH SURFACE DUE TO SOUND PROFILE
0413      C RV21,RV32=REFLECTION COEFFICIENTS FOR RESPECTIVE INTERFACE
0414      C RSIN2=SIN OF GRAZING ANGLE IN HIGH SPEED LAYER
0415      C RDTS,RDTR=REFLECTION PATH DELTA T FOR SOURCE,RECEIVER RESP.
0416      C RT=TRAVEL TIME FOR REFLECTION PATH
0417      C RGI=GEOMETRIC INTENSITY OF REFLECTION PATH
0418      C*****

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0419 C COMPUTE HSAP
0420 PI=3.141592654
0421 NSAP=1
0422 IF(C1-GE-CS)GO TO 100
0423 SAP=ACOS(C1/CS)*180/PI
0424 NSAP=SAP+1
0425 WRITE(1,1) SAP
0426 I FORMAT=' SMALLEST ANGLE TO REACH SURFACE=',FB.2)
0427 100 CONTINUE
0428 C COMPUTE REFLECTION COEFFICIENTS FOR ANGLES GREATER THAN TIR,SAP
0429 NTIR=TIR*180/PI+1
0430 N=MAX0(NTIR,HSAP)
0431 Z1=RN1*CI
0432 Z2=RH2*C2
0433 Z3=RH3*C3
0434 DELT=PI/180
0435 TH=(HSAP-1)*DELT
0436 FAC2=C2/C1
0437 FAC3=C3/C1
0438 FACS=CS/C1
0439 AR=2*ZR/CS
0440 AS=2*ZS/CS
0441 D1=2*ZB-ZR-ZS
0442 DO 200 I=NSAP,90
0443 TH=TN+DELT
0444 CTN=COS(TH)
0445 C SURFACE SCATTERING TRAVEL TIME DIFFERENCES
0446 S=SQRT(1-(FACS*CTH)**2)
0447 ROTS(I)=AS*S
0448 ROTR(I)=AR*S
0449 IF(I.LT.H)GO TO 200
0450 C SIN2
0451 RSIH2(I)=SQRT(1-(FAC2*CTN)**2)
0452 C REFLECTION COEFFICIENTS
0453 A1=Z1/SIH(TH)
0454 A2=Z2/RSIH2(I)
0455 A3=Z3/SQRT(1-(FAC3*CTN)**2)
0456 RV32(I)=(A3-A2)/(A3+A2)
0457 RV21(I)=(A2-A1)/(A2+A1)
0458 C TRAVEL TIME
0459 R=D1/TAH(TH)
0460 RT(I)=R/(CTH*C1)
0461 C GEOMETRIC INTENSITY(AMPLITUDE)
0462 RGI(I)=CTH/R
0463 200 CONTINUE
0464 RETURN
0465 END
0466 SUBROUTINE REFR
0467 COMMON ZB,ZR,ZS,C1,C2,C3,RN1,RN2,RN3,G,D,ALPH0,CS,BZ,REF,HEAD(20)
0468 COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71,F71,DBLOSS,
0469 IFREQ,THETA,ALOSS0,ALOSSM,FM,TIR,TNC,TNRC,TNIB,BETA
0470 COMMON /ALPN/GAM
0471 REAL LZERO,L70,L71
0472 COMMON /B/BV21,BV32,BSIH2,BTRF,BGI,BLS,BT,BOTS,BDTR
0473 COMMON /S/SV21,SV32,SSIN2,STRF,SGI,SLS,ST,SOTS,SDTR
0474 DIMENSION BV21(90),BV32(90),BSIH2(90),BTRF(90),BGI(90),
0475 BLS(90),BT(90),BOTS(90),BDTR(90)
0476 DIMENSION SV21(90),SV32(90),SSIN2(90),STRF(90),SGI(90),
0477 SLS(90),ST(90),SOTS(90),SDTR(90)
0478 C*****

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0479 C FOR EACH SPECULAR BOTTOM ANGLE BETWEEN THE ANGLE OF TOTAL INTERNAL REF
0480 C REFLECTION AND THE CRITICAL ANGLE THIS SUBROUTINE RETURNS REF
0481 C (SMALL BOTTOM ANGLE PREFIX S,BIG BOTTOM ANGLE PREFIX B) REF
0482 C V21,V32=REFLECTION COEFFICIENTS AT INTERFACE REF
0483 C SIN2=SIN OF GRAZING ANGLE IN HIGH SPEED LAYER REF
0484 C TRF=TRANSMISSION COEFFICIENT FACTOR REF
0485 C GI=GEOMETRIC INTENSITY REF
0486 C LS=ARC LENGTH OF RAY IN THE BOTTOM REF
0487 C T=TRAVEL TIME REF
0488 C DTS,DTX=DELTA T FOR SURFACE REFLECTION FOR SOURCE,RECEIVER RESP. REF
0489 C ***** REF
0490 PI=3.141592654 REF
0491 NTIR=TIR*180/PI+1 REF
0492 NTNC=TNC*180/PI+1 REF
0493 N=NTNC-NTIR REF
0494 DEL=PI/180 REF
0495 TN=(NTHC-1)*DEL REF
0496 Z1=RN1*C1 REF
0497 Z2=RN2*C2 REF
0498 Z3=PN3*C3 REF
0499 FAC2=C2/C1 REF
0500 FAC3=C3/C1 REF
0501 FACS=CS/C1 REF
0502 SEST=TNRC REF
0503 REF
0504 D1=2*ZB-ZR-ZS REF
0505 D2=2*C3**2/G/C1 REF
0506 D3=2*C3/G*BETA/(1+BETA) REF
0507 D4=BETA/(1+BETA)/G REF
0508 D7=1+BETA REF
0509 D5=D1/C1 REF
0510 D6=2/CS REF
0511 ANU=BETA*C3 REF
0512 SIG=G*(1+BETA)*C3 REF
0513 AMU=C3**2*(1+BETA)**2 REF
0514 D8=2*C3/G/(1+BETA)/ALPH0 REF
0515 D9=-GAM*C3**2/SIG/6 REF
0516 D10=(BETA*GAM*C3**2+GAM*ANU*C3**2)/4/SIG REF
0517 D11=-3*D9 REF
0518 D12=(GAM*(ANU**2-AMU)+2*ALPH0*SIG+2*BETA*ANU*C3*GAM)/2/SIG REF
0519 D14=BETA*GAM*(ANU**2-AMU)/2/SIG+BETA*ALPH0 REF
0520 DO 10 I=1,90 REF
0521 BTRF(I)=0 REF
0522 10 STRF(I)=0 REF
0523 DO 100 J=1,N REF
0524 J=NTNC-I REF
0525 R=D1/TAN(TN) REF
0526 CALL REFN(TN,SEST,BEST,SA,SAT,BA,BA3) REF
0527 IF(BA,GT,THIB)GO TO 998 REF
0528 BC1=COS(BA) REF
0529 BS1=SQRT(1-BC1**2) REF
0530 BC2=FAC2*BC1 REF
0531 BS2=SQRT(1-BC2**2) REF
0532 BC3=FAC3*BC1 REF
0533 BS3=SQRT(1-BC3**2) REF
0534 C BIG ANGLE REFLECTION COEFFICIENT REF
0535 A1=Z1/BS1 REF
0536 A2=Z2/BS2 REF
0537 A3=Z3/BS3 REF
0538 RV12(J)=-(A3-A2)/(A3+A2) REF

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05339 BV21(J)=(A2-A1)/(A2+A1)
0540 BTRF(J)=16*A1*A3*(A2/(A3+A2)/(A2+A1))*2
0541 BSIN2(J)=BS2
0542 C GEOMETRIC AMPLITUDE
0543 DRDT=-D1/BS1**2+D2*(BS1/BS3/BC3**2)*(1.+BA3*
0544 TAN(BA3)/D7)
0545 BGI(J)=BC1/(R*BS1*ABS(DRDT))
0546 BGI(J)=SORT(BGI(J))
0547 C ARC LENGTH
0548 BLS(J)=D8/BC3*(D9/BC3**3*BS3**3+D10/BC3*BS3
0549 1*(D11/BC3**3+D12/BC3)*BS3*(D10/BC3**2+D14)*BA3)
0550 TRAVEL TIME
0551 BT(J)=D5/BS1+D4*(ALOG((1+BS3)/(1-B33)))+(2*BA3/BC3/BETA)
0552 C DELTA T SOURCE RECEIVER
0553 BS9=SORT(1-(FACS*BC1)**2)
0554 BDTK(J)=D6*ZS*BSS
0555 BDTK(J)=D6*ZS*BSS
0556 SC1=COS(SA)
0557 IF(9A.GT.TNIB)GO TO 999
0558 AUX=FACS*SC1
0559 C IF RAY DOES NOT REACH SURFACE NOT COMPUTED
0560 IF(AUX.GT.1.)GO TO 999
0561 C DELTA T SOURCE RECEIVER
0562 SSS=SORT(1-AUX**2)
0563 SDTR(J)=D6*ZS*SS9
0564 SDTS(J)=D6*ZS*SSS
0565 SS1=SORT(1-SC1**2)
0566 SC2=FAC2*SC1
0567 SS2=SORT(1-SC2**2)
0568 SC3=FAC3*SC1
0569 SS3=SORT(1-SC3**2)
0570 C SMALL ANGLE REFLECTION COEFFICIENT
0571 A1=Z1/SS1
0572 A2=Z2/892
0573 A3=Z3/SS3
0574 SV32(J)=(A3-A2)/(A3+A2)
0575 SV21(J)=(A2-A1)/(A2+A1)
0576 STRF(J)=16*A1*A3*(A2/(A3+A2)/(A2+A1))*2
0577 SSIN2(J)=SS2
0578 C GEOMETRIC AMPLITUDE
0579 DRDT=-D1/SS1**2+D2*(SS1/SS3/SC3**2)*(1+SA3*TAN(SA3)/D7)
0580 SGI(J)=SC1/(R*SS1*ABS(DRDT))
0581 SGI(J)=SORT(SGI(J))
0582 C ARC LENGTH
0583 SLS(J)=D8/SC3*(D9/SC3**3*SS3**3+D10/SC3*SS3
0584 1*(D11/SC3**3+D12/SC3)*SS3*(D10/SC3**2+D14)*SA3)
0585 TRAVEL TIME
0586 ST(J)=D5/SS1+D4*(ALOG((1+SS3)/(1-SS3)))+(2*SA3/SC3/BETA)
0587 TH=TN-DEL
0588 100 CONTINUE
0589 RETURN
0590 END
0591 SUBROUTINE BASE
0592 C*****
0593 C FOR EACH SPECTRAL BOTTOM ANGLE SUB RETURNS
0594 C BSV21,BSV32=REFLECTION COEFFICIENTS AT INTERFACE
0595 C ASSIN2= SIN OF GRAZING ANGLE IN HIGH SPEED LAYER
0596 C BSTPF=TRANSMISSION COEFFICIENT FACTOR
0597 C BSG1=GEOMETRIC AMPLITUDE
0598 C BSL5=ARC LENGTH OF RAY IN BOTTOM
0599 C

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0599 C BST=TRAVEL TIME
0600 C BSDTS,BSDTR=DELTA T FOR SURFACE REFLECTION FOR SOURCE RECEIVER
0601 C*****
0602 COMMON ZB,ZR,ZS,C1,C2,C3,RN1,RN2,RN3,G,D,ALPH0,CS,BZ,REF,HEAD<20>
0603 COMMON /DATA/LZERO,FZER0,L70,F70,TN70,L71,F71,DBLOSS,FREQ,THETA,
0604 IALOSS0,ALOSSH,M,TIR,THC,TNRC,TH1B,BETA
0605 COMMON /BS/BSV21,BSV32,BSSIN2,BSTRF,BSGI,BSLS,BST,BSDTS,BSDTR
0606 DIMENSION BSV21(90),BSV32(90),BSSIN2(90),BSTRF(90),BSGI(90),
0607 IBLS<90>,BST<90>,BSDTS<90>,BSDTR(90)
0608 COMMON /ALPN/GAM
0609 REAL LZERO,L70,L71
0610 PI=3.141592654
0611 HTIR=TIR*180/PI+1
0612 DEL=PI/180
0613 TH=PI/2
0614 Z1=RH1*C1
0615 Z2=RH2*C2
0616 Z3=RH3*C3
0617 FAC2=C2/C1
0618 FAC3=C3/C1
0619 FACS=CS/C1
0620 CB=9QRT<(2*G*(1+BETA)*C3*BZ+(C3*(1+BETA))*2)-BETA*C3
0621 FACB=CB/C1
0622 D1=2*ZB-ZR-ZS
0623 D2=2*C3**2/C1/G/(1+BETA)
0624 D3=2*C3/G/(1+BETA)
0625 D4=2/G/(1+BETA)
0626 D5=D1/C1
0627 D6=2/CS
0628 D7=2*C3*BETA/G/(1+BETA)/C1
0629 THE FOLLOWING 2 LINES ADDED 5/29/79
0630 DA=2.*C3/G/(1.+BETA)
0631 DB=DA*BETA
0632 ANU=BETA*C3
0633 SIG=G*(1+BETA)*C3
0634 AMU=C3**2*(1+BETA)**2
0635 D8=2*C3/G/(1+BETA)/ALPH0
0636 D9=-GAM*C3**2/SIG/6
0637 D10=(BETA*GAM*C3**2+GAM*ANU*C3*2)/4/SIG
0638 D11=-3*D9
0639 D12=(GAM*(ANU**2-AMU)+2*ALPH0*SIG+2*BETA*AHU*C3*GAM)/2/SIG
0640 D14=BETA*GAM*(ANU**2-AMU)/2/SIG+BETA*ALPNO
0641 BSA=TH-1.E-6
0642 TN3=ACOS(FAC3*COSEC(TH1B))
0643 R=D1/TAN(TN1B)+D3/COS(TH3)**2*(TH3/2+(.25*BETA/2)*SIN(2*TH3))
0644 AUX=ATAN(D1/R)
0645 N=AUX*180/PI+1
0646 N=90-MAX(0,H,HTIR)
0647 DO 10 I=1,90
0648 BSSIH2(I)=0.0
0649 BSV32(I)=0.0
0650 BSV21(I)=0.0
0651 BSGI(I)=0.0
0652 BSTRF(I)=0
0653 DO 100 I=1,N
0654 J=90-I
0655 TH=TH-DEL
0656 CALL BASANG(TH,BSA,BSATJ)
0657 IF(RSA3.EQ.0.0) GO TO 100
0658 RC1=COS(RSA)

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[illegible]



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0719 STOP
0720 100 D1=2*ZB-ZR-ZS
0721 P12=3.141592654
0722 P12=P12/2
0723 D2=2*C3/G*(BETA/(1+BETA))
0724 D3=1/(2*BETA)
0725 FAC3=C3/C1
0726 R=D1/TAN(TH)
0727 T3=ACOS(FAC3*COS(SEST))
0728 VAL=D1/TAN(SEST)+D2*TAN(T3)*(1+(1+T3/SIN(T3)/COS(T3))*D3)-R
0729 DEL=(SEST-TIR)/10.0001
0730 C COMPUTE SA
0731 102 DO 200 I=1,500
0732 IF(ABS(DEL).LT.1.E-6) GO TO 201
0733 SA=SEST-DEL
0734 IF(SA.LE.TIR)GO TO 211
0735 IF(SA.GE.THRC)GO TO 211
0736 T3=ACOS(FAC3*COS(SA))
0737 VALP=D1/TAN(SA)+D2*TAN(T3)*(1+(1+T3/SIN(T3)/COS(T3))*D3)-R
0738 AUX=VAL*VALP
0739 SEST=SA
0740 VAL=VALP
0741 IF(AUX.GT.0.)GO TO 200
0742 DEL=-DEL/3
0743 GO TO 200
0744 211 DEL=DEL/3
0745 200 CONTINUE
0746 WRITE(1,2)
0747 2 FORMAT(' SMALL BOTTOM REFRACTION ANGLE DOES NOT CONVERGE')
0748 STOP
0749 201 SA3=T3
0750 C BA INITIALIZATION
0751 T3=ACOS(FAC3*COS(BEST))
0752 VAL=D1/TAN(BEST)+D2*TAN(T3)*(1+(1+T3/SIN(T3)/COS(T3))*D3)-R
0753 DEL=(P12-BEST)/10.0001
0754 C COMPUTE BA
0755 302 DO 400 I=1,500
0756 IF(ABS(DEL).LT.1.E-6) GO TO 401
0757 BA=BEST+DEL
0758 IF(BA.LE.THRC)GO TO 411
0759 IF(BA.GE.P12)GO TO 411
0760 T3=ACOS(FAC3*COS(BA))
0761 VALP=D1/TAN(BA)+D2*TAN(T3)*(1+(1+T3/SIN(T3)/COS(T3))*D3)-R
0762 AUX=VAL*VALP
0763 BEST=BA
0764 VAL=VALP
0765 IF(AUX.GT.0.)GO TO 400
0766 DEL=-DEL/3
0767 GO TO 400
0768 411 DEL=DEL/3
0769 400 CONTINUE
0770 WRITE(1,3)
0771 3 FORMAT(' LARGE BOTTOM REFRACTION ANGLE DOES NOT CONVERGE')
0772 STOP
0773 401 BA3=T3
0774 RETURN
0775 END
0776 SUBROUTINE BASANG(TH,ASA,BSA3)
0777 COMMON ZB,ZR,ZS,C1,C2,C3,PH1,PH2,PH3,G,D,ALPH0,CS,BZ,REF,HEAD(20)
0778 COMMON /DATA1/ZERO,FZERO,L70,F70,TH70,L71,F71,DRLOSS,FREQ,THETA,

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0779      IALOSS0,ALOSSM,FM,TIR,INC,THRC,TN1B,BETA      BASANG
0780      REAL LZ00,L70,L71      BASANG
0781      C*****      BASANG
0782      C GIVEN      BASANG
0783      C 82=SEDIMENT DEPTH      BASANG
0784      C TH1B=BASEMENT CRITICAL ANGLE      BASANG
0785      C TIR=ANGLE OF TOTAL INTERNAL REFLECTION      BASANG
0786      C TH=GRAZING ANGLE      BASANG
0787      C RETURNS      BASANG
0788      C 8SA=BASEMENT REFLECTED RAY ANGLE IN WATER      BASANG
0789      C 8SA3=BASEMENT REFLECTED RAY ANGLE IN SEDIMENT      BASANG
0790      C*****      BASANG
0791      IF<TH,GT,TIR>GO TO 100
0792      WRITE<1,1>
0793      1 FORMAT<" SPECULAR ANGLE OF BASEMENT RAY LESS THAN TIR">      BASANG
0794      STOP      BASANG
0795      100 D1=2*ZB-2R-ZS      BASANG
0796      P1=3.141592654      BASANG
0797      P12=P1/2      BASANG
0798      D2=2*C3/G/(1+BETA)      BASANG
0799      FAC3=C3/C1      BASANG
0800      CB=SQRT<2*C*(1+BETA)*C3*BZ+(C3*(1+BETA))*2>-BETA*C3      BASANG
0801      FACB=CB/C1      BASANG
0802      R=D1/TAH<TN>      BASANG
0803      BEST=BSA      BASANG
0804      AUX=COS<BEST>      BASANG
0805      TNB=ACOS<FACB*AUX>      BASANG
0806      TN3=ACOS<FAC3*AUX>      BASANG
0807      VAL=D1/TAH<BEST>*02/(FAC3*AUX)**2*(TN3-TNB)/2+      BASANG
0808      1<SIN<2*TN3>-SIN<2*TNB>/4+BETA*(FAC3*AUX)*(SIN<TN3>-SIN<TNB>))>-R      BASANG
0809      DEL=P1/180      BASANG
0810      AUX=TIR      BASANG
0811      IF<TN1B,GT,TIR>AUX=TN1B      BASANG
0812      101 IF<BEST-DEL>,GT,AUX>GO TO 102      BASANG
0813      DEL=DEL*.9      BASANG
0814      GO TO 101      BASANG
0815      C COMPUTE BSA      BASANG
0816      102 DO 200 I=1,500      BASANG
0817      BSA=BEST-DEL      BASANG
0818      IF<BSA,LE,AUX>GO TO 211      BASANG
0819      IF<BSA,GE,P12>GO TO 211      BASANG
0820      AUX1=COS<BSA>      BASANG
0821      TNB=ACOS<FACB*AUX1>      BASANG
0822      TH3=ACOS<FAC3*AUX1>      BASANG
0823      VALP=D1/TAH<BSA>*02/(FAC3*AUX1)**2*(TN3-TNB)/2+      BASANG
0824      1<SIN<2*TN3>-SIN<2*TNB>/4+BETA*(FAC3*AUX1)*(SIN<TN3>-SIN<TNB>))>-R      BASANG
0825      BAUX=VAL*VALP      BASANG
0826      BEST=BSA      BASANG
0827      VAL=VALP      BASANG
0828      IF<BAUX,GT,0.0>GO TO 200      BASANG
0829      VAL=VALP      BASANG
0830      210 DEL=-DEL/3      BASANG
0831      IF<ABS<DEL>,LT,1.E-6>GO TO 201      BASANG
0832      GO TO 200      BASANG
0833      211 DEL=DEL/3      BASANG
0834      200 CONTINUE      BASANG
0835      BSA=P1/2.0-1.0E-6      BASANG
0836      TH3=0.0      BASANG
0837      WRITE<1,2>      BASANG
0838      2 FORMAT<" BASEMENT ANGLE DOES NOT CONVERGE">      BASANG
0839      201 BSA1=TH3      BASANG

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0839 RETURN
0840 END
0841 SUBROUTINE LOSS(JJ)
0842 COMMON ZB,ZR,ZS,C1,C2,C3,RN1,RN2,RN3,G,D,ALPN9,CS,BZ,REF,HEAD(20)
0843 COMMON /DATA/LZERO,FZERO,L70,F70,TH70,L71,F71,DBLOSS,FREQ,TNETA,
0844 IALOSS0,ALOSSM,FM,TIR,TNC,TNRC,TN18,BETA
0845 COMMON /AL/F(6),ALOSS(6,90)
0846 COMMON /R/NSAP,RV21,RV32,RSIN2,RDTS,RDTR,RT,RGI
0847 DIMENSION RV21(90),RV32(90),RSIN2(90),RDTS(90),RDTR(90),RT(90),
0848 RGI(90)
0849 COMMON /B/BV21,BV32,BSIN2,BTRF,BGI,BLS,BT,BDTS,BDTR
0850 COMMON /S/SV21,SV32,SSIN2,STRF,SGI,SLS,ST,SDTS,SDTR
0851 DIMENSION BV21(90),BV32(90),BSIN2(90),BTRF(90),BGI(90),
0852 BLS(90),BT(90),BDTS(90),BDTR(90)
0853 DIMENSION SV21(90),SV32(90),SSIN2(90),STRF(90),SGI(90),
0854 SLS(90),ST(90),SDTS(90),SDTR(90)
0855 COMMON /BS/BSV21,BSV32,BSSIN2,BSTRF,BSGI,BSLS,BST,BSDTS,BSDTR
0856 DIMENSION BSV21(90),BSV32(90),BSSIN2(90),BSTRF(90),BSGI(90),
0857 BLS(90),BST(90),BSDTS(90),BSDTR(90)
0858 COMPLEX AUX99,V,AIM,AUX1,AR(16),PK(16)
0859 DIMENSION BR(4)
0860 REAL LZERO,L70,L71
0861 C*****
0862 C THIS SUBROUTINE COMPUTES APPARENT LOSS DUE TO PROPAGATION
0863 C*****
0864 PI=3.141592654
0865 ALPH0=ALOG(10.)/4/PI/10000*ALPN9
0866 EX=ALOG10(EXP(1.))
0867 PI2=2*PI
0868 AIM=CMPLX(0.,1.)
0869 SORT2=SQRT(2.)
0870 F1=F(JJ)/SQRT2
0871 F2=F(JJ)*SQRT2
0872 FPI2D=4.*PI*F(JJ)*D/C2
0873 NAV1=8
0874 FPIINC = FPI2D*(SQRT2-1.0/SQRT2)/NAV1
0875 FPIIN=FPI2D-(NAV1-1)*FPIINC/2.
0876 NTNC=TNC*180/PI
0877 N=90-NTNC
0878 C COMPUTE LOSS FOR ANGLES ABOVE CRITICAL (CAUSTIC)
0879 DO 10 I=1,90
0880 10 ALOSS(JJ,I)=25.
0881 DO 100 I=1,N
0882 J=91-I
0883 FPIAUX=FPIIN
0884 AUX=0.
0885 DO 20 NAV=1,NAV1
0886 ALPH2=FPIAUX*RSIN2(J)
0887 C=COS(ALPH2)
0888 S=SIN(ALPH2)
0889 VV=(RV21(J)+RV32(J)*C)**2+(RV32(J)*S)**2
0890 VV=VV/((1+RV21(J)*RV32(J)*C)**2+(RV21(J)*RV32(J)*S)**2)
0891 AUX=AUX+VV
0892 FPIAUX=FPIAUX+FPIINC
0893 20 CONTINUE
0894 VV=AUX/NAV1
0895 DR=PI2*RDTR(J)
0896 DS=PI2*BDTS(J)
0897 AUX=DR+DS
0898 DT=SIN(CF2+AUX)-SIN(CF1+AUX)

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0899 DT=DT/AUX
0900 AUX=DS-DR
0901 DT=DT+SIN(F2*AUX)/AUX-SIN(F1*AUX)/AUX
0902 DT=DT-2*(SIN(F2*DS)-SIN(F1*DS))/DS
0903 DT=DT-2*(SIN(F2*DR)-SIN(F1*DR))/DR
0904 DT=DT/2/F1+1
0905 DT=VV*DT
0906 ALPN2=FPI2D*BSSIN2(J)/2
0907 C=COS(ALPH2)
0908 S=SIN(ALPH2)
0909 V=BSTRF(J)/CMPLX((1+BSV32(J)*BSV21(J))*C,
0910 1(BSV32(J)*BSV21(J)-1)*S)**2
0911 VV=CABS(V)*BSG(J)*REF
0912 AUX=0
0913 IF(VV.EQ.0.)GO TO 120
0914 BR(1)=VV
0915 BR(2)=-VV
0916 BR(3)=VV
0917 BR(4)=VV
0918 V=CMPLX(BST(J),ALPN0*BSLS(J))
0919 PN(1)=PI2*V
0920 PH(2)=PI2*(V+BSDT(J))
0921 PN(3)=PI2*(V+BSDTR(J))
0922 PN(4)=PI2*(V+BSDTR(J)+BSDT(J))
0923 V=0
0924 DO 110 K=1,3
0925 NA=K+1
0926 DO 110 L=NA,4
0927 AUX=BR(K)*BR(L)
0928 AUX1=(PH(K)-CONJG(PN(L)))*AIM
0929 IF(REAL(AUX1)*F2.LT.-40.)GO TO 110
0930 V=V+AUX*(CEXP(F2*AUX1)-CEXP(F1*AUX1))/AUX1
0931 110 CONTINUE
0932 AUX=2*REAL(V)
0933 AUX2=-2*PI2*ALPN0*BSLS(J)
0934 IF(AUX2*F2.LT.-40.)GO TO 120
0935 AUX=AUX+4*(CEXP(F2*AUX2)-EXP(F1*AUX2))/AUX2*BR(1)**2
0936 DT=DT+AUX/(2*RG1(J))*2/F1
0937 ALOSS(J,J)=-10.*ALOG10(DT)
0938 100 CONTINUE
0939 NMAX=91-N
0940 C COMPUTE LOSS FOR ANGLES BETWEEN TIR AND TNS
0941 NTIR=TIR*180/PI+1
0942 N=NMAX-NTIR
0943 DO 200 I=1,N
0944 J=NMAX-I
0945 IF(J.LT.NSAP)GO TO 800
0946 C COMPUTE REFLECTION COEFFICIENT
0947 C
0948 COMPUTE FREQ AVERAGE ABSOLUTE REFLECTION
0949 FPIAUX=FPIIN
0950 AUX=0
0951 DO 130 NAV=1,NAV1
0952 ALPN2=FPIAUX*PSIN2(J)
0953 C=COS(ALPH2)
0954 S=SIN(ALPH2)
0955 VV=(RV21(J)+RV32(J)*C)**2+(RV32(J)*S)**2
0956 VV=VV/(1+RV21(J)+RV32(J)*C)**2+(RV21(J)*S)**2)
0957 AUX=AUX+VV
0958 FPIAUX=FPIAUX+FPIIN

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0959 130 CONTINUE
0960 VV=AUX/NAV1
0961 ALPH2=FP12D*RSIN2(J)
0962 C=COS(ALPH2)
0963 S=SIN(ALPH2)
0964 V=CMPLX(RV21(J)+RV32(J)*C,RV32(J)*S)
0965 V=V/CMPLX(1+RV21(J)+RV32(J)*C,RV21(J)+RV32(J)*S)
0966 V=V/CARS(V)*RGI(J)*SORT(VV)
0967 AR(1)=V
0968 AR(2)=-V
0969 AR(3)=-V
0970 AR(4)=V
0971 PH(1)=PI2*RT(J)
0972 PH(2)=PI2*(RT(J)+RDTSC(J))
0973 PH(3)=PI2*(RT(J)+RDIR(J))
0974 PH(4)=PI2*(RT(J)+RDIR(J)+RDTSC(J))
0975 C COMPUTE BIG TRANSMISSION COEFFICIENT
0976 AR(5)=0
0977 AR(6)=0
0978 AR(7)=0
0979 AR(8)=0
0980 IF(8TRF(J).EQ.0.)GO TO 205
0981 IF(BT(J).LT.RT(J))GO TO 205
0982 ALPH2=FP12D*BSIN2(J)/2
0983 C=COS(ALPH2)
0984 S=SIN(ALPH2)
0985 V=BTFR(J)/CMPLX((1+BV32(J)+BV21(J))*C,(BV32(J)+BV21(J)-1)*S)**2
0986 V=V*BGI(J)
0987 AR(5)=V
0988 AR(6)=-V
0989 AR(7)=-V
0990 AR(8)=V
0991 V=CMPLX(BT(J),ALPH0*BLS(J))
0992 PH(5)=PI2*V
0993 PH(6)=PI2*(V+BDTS(J))
0994 PH(7)=PI2*(V+BDTR(J))
0995 PH(8)=PI2*(V+BDTS(J)+BDTR(J))
0996 205 CONTINUE
0997 C COMPUTE SMALL TRANSMISSION COEFFICIENT
0998 ALPH2=FP12D*SSIN2(J)/2
0999 C=COS(ALPH2)
1000 S=SIN(ALPH2)
1001 V=STFR(J)/CMPLX((1+SV32(J)+SV21(J))*C,(SV32(J)+SV21(J)-1)*S)**2
1002 V=-V*SGI(J)*AIM
1003 AR(9)=V
1004 AR(10)=-V
1005 AR(11)=-V
1006 AR(12)=V
1007 V=CMPLX(ST(J),ALPH0*SLS(J))
1008 PH(9)=PI2*V
1009 PH(10)=PI2*(V+SDTS(J))
1010 PH(11)=PI2*(V+SDTR(J))
1011 PH(12)=PI2*(V+SDTS(J)+SDTR(J))
1012 C COMPUTE BASEMENT RAY TRANSMISSION COEFFICIENT
1013 ALPH2=FP12D*BSSIN2(J)/2
1014 C=COS(ALPH2)
1015 S=SIN(ALPH2)
1016 V=BSSTFR(J)/CMPLX((1+BSV32(J)+BSV21(J))*C,
1017 1*(BSV32(J)+BSV21(J)-1)*S)**2
1018 V=V*BSGI(J)*PEF

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1019 AR(13)=V LOSS
1020 AR(14)=-V LOSS
1021 AR(15)=-V LOSS
1022 AR(16)=V LOSS
1023 V=CMPLX(BST(J),ALPH0*BSLS(J)) LOSS
1024 PH(13)=PI2*V LOSS
1025 PH(14)=PI2*(V+BSDTS(J)) LOSS
1026 PH(15)=PI2*(V+BSDTR(J)) LOSS
1027 PH(16)=PI2*(V+BSDTS(J)+BSDTR(J)) LOSS
1028 V=0 LOSS
1029 DO 210 K=1,15 LOSS
1030 NA=K+1 LOSS
1031 DO 210 L=HA,16 LOSS
1032 AUX99=AR(K)*COHJC(AR(L)) LOSS
1033 IF(CABS(AUX99).EQ.0.)GO TO 210 LOSS
1034 AUX1=(PH(K)-COHJC(PH(L)))*AIM LOSS
1035 IF(REAL(AUX1)*F2.LT.-40)GO TO 210 LOSS
1036 V=V+AUX99*(CEXP(F2*AUX1)-CEXP(F1*AUX1))/AUX1 LOSS
1037 210 CONTINUE LOSS
1038 AUX=2*REAL(V) LOSS
1039 IF(CABS(AR(13)).EQ.0.)GO TO 209 LOSS
1040 AUX2=-2*PI2*ALPH0*BSLS(J) LOSS
1041 IF(AUX2*F2.LT.-40)GO TO 209 LOSS
1042 AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/AUX2*CABS(AR(13))*2 LOSS
1043 AUX2=-2*PI2*ALPH0*BSLS(J) LOSS
1044 AUX2=-2*PI2*ALPH0*BSLS(J) LOSS
1045 IF(AUX2*F2.LT.-40)GO TO 211 LOSS
1046 IF(CABS(AR(5)).EQ.0.)GO TO 211 LOSS
1047 AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/AUX2*CABS(AR(5))*2 LOSS
1048 AUX2=-2*PI2*ALPH0*BSLS(J) LOSS
1049 IF(AUX2*F2.LT.-40)GO TO 212 LOSS
1050 IF(CABS(AR(9)).EQ.0.)GO TO 212 LOSS
1051 AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/AUX2*CABS(AR(9))*2 LOSS
1052 AUX=AUX/F1+4*CABS(AR(1))*2 LOSS
1053 IF(AUX.GT.0.)GO TO 213 LOSS
1054 ALO98(JJ,J)=25. LOSS
1055 GO TO 200 LOSS
1056 213 ALO98(JJ,J)=-10.*ALOG10(AUX/(2.*RG1(J))*2) LOSS
1057 200 CONTINUE LOSS
1058 700 H=J-1 LOSS
1059 NA=J LOSS
1060 DO 701 I=1,N LOSS
1061 J=NA-I LOSS
1062 IF(J.LT.NSAP)GO TO 999 LOSS
1063 DR=PI2*RDTR(J) LOSS
1064 DS=PI2*RDTS(J) LOSS
1065 AUX=DR+DS LOSS
1066 DT=SIN(F2*AUX)-SIN(F1*AUX) LOSS
1067 DT=DT/AUX LOSS
1068 AUX=DS-DR LOSS
1069 DT=DT+SIN(F2*AUX)/AUX-SIN(F1*AUX)/AUX LOSS
1070 DT=DT-2*(SIN(F2*DS)-SIN(F1*DS))/DS LOSS
1071 DT=DT-2*(SIN(F2*DR)-SIN(F1*DR))/DR LOSS
1072 DT=DT/2/F1+1 LOSS
1073 ALO98(JJ,J)=-10.*ALOG10(DT) LOSS
1074 701 CONTINUE LOSS
1075 GO TO 999 LOSS
1076 NA=J-1 LOSS
1077 NA=J LOSS
1078 DO 801 I=1,N LOSS

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1079 J=NA-I
1080 IF(J.LT.NTIP)GO TO 999
1081 C COMPUTE BIG TRANSMISSION COEFFICIENT
1082 ALOSS(JJ,J)=25.
1083 ALPH2=FP12D*BSINH2(J)
1084 C=COS(ALPH2)
1085 S=SIN(ALPH2)
1086 V=BTFR(J)/CMPLX((I+BV32(J)*BV21(J))*C,(BV32(J)*BV21(J)-I)*S)**2
1087 V=V*BCI(J)
1088 AUX3=CABS(V)**2
1089 IF(AUX3.EQ.0)GO TO 801
1090 DR=P12*80TR(J)
1091 DS=P12*80TS(J)
1092 AUX=DR+DS
1093 DT=SIN(F2*AUX)-SIN(F1*AUX)
1094 DT=DT/AUX
1095 AUX=DS-DR
1096 DT=DT+SIN(F2*AUX)/AUX-SIN(F1*AUX)/AUX
1097 DT=DT-2*(SIN(F2*DS)-SIN(F1*DS))/DS
1098 DT=DT-2*(SIN(F2*DR)-SIN(F1*DR))/DR
1099 DT=DT/2/F1+I
1100 AUX2=-2*P12*ALPH0*8LS(J)*EX
1101 IF(AUX2*F2.LT.-40.)GO TO 801
1102 ALOSS(JJ,J)=-10*(AUX2+ALOG10(AUX3*DT/RCI(J)**2))
1103 IF(ALOSS(JJ,J).GT.25.)ALOSS(JJ,J)=25
1104 CONTINUE
1105 RETURN
1106 END
1107 SUBROUTINE GCOMP
1108 C
1109 C THIS SUBROUTINE COMPUTES THE GRADIENT (G)
1110 C AND ITERATES TO FIND THE ACTUAL CRITICAL
1111 C ANGLE (THC). BOTH ARE THEN RETURNED TO THE
1112 C MAIN PROGRAM.
1113 C
1114 COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,ALPH0,CS,BZ,REF,HEAD(20)
1115 COMMON /DATA/LZERO,FZERO,L70,F70,TH70,L71,F71,DBLOSS,FREQ,THETA,
1116 1 ALOSS0,ALOSSM,FM,TIR,THC,THRC,TH18,BETA
1117 REAL LZERO,L70,L71
1118 PI=3.14159265
1119 THRC=30.
1120 THC0=THC
1121 B=BETA
1122 THRC=THRC*(PI/180.)
1123 THINC=1.
1124 DI=2*ZB-ZR-ZS
1125 TH3=ACOS((C3/C1)*COS(THRC))
1126 FACT1=(2.*C3*8)/(1.+B)
1127 SIN3=SIN(TH3)
1128 COS3=COS(TH3)
1129 SIN3SQ=SIN3*SIN3
1130 COS3SQ=COS3*COS3
1131 FACT2=1.+(1./(2.*8))*(1.+(TH3/(SIN3*COS3)))
1132 GZERO=(FACT1*(1./COS3SQ)*FACT2*(C3/(1.+B))
1133 1 *(1./COS3SQ)*(1.-(TH3*(COS3SQ-SIN3SQ))/(SIN3*COS3)))
1134 2 *(C3/C1)*(SIN(THRC)/SIN3)/(DI/SIN(THRC)**2)
1135 R=(DI/TAN(THRC))*(FACT1*TAN(TH3)/GZERO)*FACT2
1136 THC1=ATAN(DI/R)
1137 THCI=THC1*(180./PI)
1138 MAXIT=100

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1139      100 DO 600 II=1,MAXIT
1140          THRC=THRC*(180./PI)
1141          THRC=THRC+THINC
1142          THRC=THRC*(PI/180.)
1143          TN3=ACOS((C3/C1)*COS(THRC))
1144          FACT1=(2.*C3*B)/(1.+B)
1145          SIN3=SIN(TN3)
1146          COS3=COS(TN3)
1147          SIN3SQ=SIN3*SIN3
1148          COS3SQ=COS3*COS3
1149          FACT2=1.+(1./(2.*B))*((1.+(TH3/(SIN3*COS3)))
1150          GZERO=(FACT1*(1./COS3SQ)*FACT2+(C3/(1.+B))
1151          1 *((1./COS3SQ)*(1.-(TH3*(COS3SQ-SIN3SQ))/(SIN3*COS3))))
1152          2 *((C3/C1)*(SIN(THRC)/SIN3))/(D1/SIN(THRC)**2)
1153          R=(D1/TAN(THRC))*((FACT1*TAN(TH3)/GZERO)*FACT2
1154          THC2=ATAN(D1/R)
1155          THC2=THC2*(180./PI)
1156          IF(ABS(THC0-THC1).LE. 1.E-4) GO TO 700
1157          IF((THC0-THC1)*(THC0-THC2)) .GE. 0.) GO TO 500
1158          THINC= -THINC/2.
1159          THC1=THC2
1160          500 CONTINUE
1161          600 CONTINUE
1162          WRITE(1,650) MAXIT,THC0,THC2
1163          650 FORMAT(1X,15,2X,"ITERATIONS AND STILL NO SOLUTION",/,
1164          1 1X,"THC0=",F10.6,5X,"THC2=",F10.6)
1165          GO TO 800
1166          700 THC=THC2
1167          G=GZERO
1168          800 RETURN
1169          END
1170          BLOCK DATA NULL
1171          COMMON /DATA/ALZERO,FZERO,AL70,F70,TH70,AL71,F71,DBLOSS,FREQ,
1172          1 THETA,ALOSS0,ALOSSM,FM,TIR,THC,THRC,TN1B,BETA
1173          COMMON /ALPH/GAM
1174          COMMON /T/T
1175          COMMON /R/HSAP,RV21(90),RV32(90),RSIN2(90),RDTs(90),RDTR(90),
1176          * RT(90),RG1(90)
1177          COMMON /B/BV21(90),BV32(90),BSIN2(90),BTRF(90),BGI(90),BLS(90),
1178          * BT(90),BDTS(90),BDTR(90)
1179          COMMON /S/SV21(90),SV32(90),SSIN2(90),STRF(90),SGI(90),SLS(90),
1180          * ST(90),SDTS(90),SDTR(90)
1181          COMMON /BS/BSV21(90),BSV32(90),BSSIN2(90),BSTRF(90),BSGI(90),
1182          * BSLs(90),BST(90),BSDTS(90),BSDTR(90)
1183          COMMON/AL/F(6),ALOSS(6,90)
1184          DATA F/50.,100.,200.,400.,800.,1600./
1185          END
1186          END$
1187          LOSS
1188          REFR
1189          MAYB2
1190          MAYB2
1191          MAYB2
1192          MAYB2
1193          MAYB2
1194          MAYB2
1195          MAYB2
1196          MAYB2
1197          MAYB2
1198          MAYB2
1199          MAYB2
1200          MAYB2
1201          MAYB2
1202          MAYB2
1203          MAYB2
1204          MAYB2
1205          MAYB2
1206          MAYB2
1207          MAYB2
1208          MAYB2
1209          MAYB2
1210          MAYB2
1211          MAYB2
1212          MAYB2
1213          MAYB2
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1279          MAYB2
1280          MAYB2
1281          MAYB2
1282          MAYB2
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1286          MAYB2
1287          MAYB2
1288          MAYB2
1289          MAYB2
1290          MAYB2
1291          MAYB2
1292          MAYB2
1293          MAYB2
1294          MAYB2
1295          MAYB2
1296          MAYB2
1297          MAYB2
1298          MAYB2
1299          MAYB2
1300          MAYB2
1301          MAYB2
1302          MAYB2
1303          MAYB2
1304          MAYB2
1305          MAYB2
1306          MAYB2
1307          MAYB2
1308          MAYB2
1309          MAYB2
1310          MAYB2
1311          MAYB2
1312          MAYB2
1313          MAYB2
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1316          MAYB2
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1319          MAYB2
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1321          MAYB2
1322          MAYB2
1323          MAYB2
1324          MAYB2
1325          MAYB2
1326          MAYB2
1327          MAYB2
1328          MAYB2
1329          MAYB2
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APPENDIX B

Flow Chart of PROGRAM BTLS



```

      /.....\
      : BEGIN :
      \...../

      I
      I
      .....
      : L :
      : PROGRAM BTLS9 :
      : .....
      I
      I---[ THIS PROGRAM SIMULATES MEASURED]
      I [BOTTOM LOSS DATA ]
      I [ INCLUDING MEASUREMENT ARTIFACTS]
      I
      I---[ BLANK COMMON CONTAINS GEOACOUST]
      I [C PARAMETERS ]
      I
      I
      .....
      : COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
      : ALPHO,CS,EZ,REF :
      : COMMON /ALPH/GAM :
      : COMMON /T/T :
      : .....
      I
      I---[ COMMON BLOCK AL CONTAINS THE ]
      I [SIX FREQUENCIES DEFINED ]
      I [ IN THE FOLLOWING DATA STATEMENT]
      I [ IN F, AND CORRESPONDING ]
      I [ BOTTOM LOSS FOR THE SIX ]
      I [FREQUENCIES AND 90 ANGLES IN ]
      I [ ALOSS. THE VALUSE IN ALOSS ARE ]
      I [CALCULATED IN SUBROUTINE LOSS. ]
      I
      I---[ ALL VALUES OF ALOSS ARE ]
      I [RETAINED, WHICH IS ]
      I [ NOT NECESSARY IN THIS VERSION ]
      I [OF THE PROGRAM. ]
      I
      I
      .....
      : COMMON/AL/F(6),ALOSS(6,90) :
      : DIMENSION BRAY(546) :
      : EQUIVALENCE (BRAY(1),F(1)),(BRAY(7), :
      : ALOSS(1,1)) :
      : .....
      I
      I---[ LOOP 500 READS A SET OF INPUT ]
      I [DATA AND GENERATES A SET ]
      I [ OF BOTTOM LOSS DATA ON EACH ]
      I [PASS UP TO A MAXIMUM ]
      I
      I---[ SUBROUTINE LOS2 CALCULATES ALL ]
      I [FREQUENCY INDEPENDENT ]
      I [ INTERMEDIATE VAPIABLES ]
      I
      I

```

```

.....
: : CALL LOS2 : :
: : .....

I
I
/ ..... \ TRUE
< IF(T.EQ.999) GO TO 999 >-----0
\ ..... /
I FALSE
I
I---[ LOOP 41 CALCULATES BOTTOM LOSS ]
I [ AT A PARTICULAR ]
I [ FREQUENCY IN SUBROUTINE LOSS ]
I [ AND PRINTS IT ]
I [ OUT ON EACH PASS. ]
I
I
.....
A----->: DO 41 J=1,6 :
A : .....
A I
A I
A .....
A : : CALL LOSS(J) : :
A : .....
A I
A I
A / ..... /
A / WRITE(6,2)(ALOSS(J,I),I=1,90) /
A / ..... /
A I
A I---[ 2 FORMAT(1X,8F8.2) ]
A I
A [ 41] I
A .....
A-----: CONTINUE :
A : .....
A I
A I
A .....
A : : CALL EXEC(14,2,BRAY,1092) : :
A : .....
A I
A I
A / ..... /
A / WRITE(1,69) /
A / ..... /
A I
A I---[69 FORMAT(' NORMAL TERMINATION -]
A I [ BOTTOM LOSS MODEL') ]
A I
A 0<-----0
[ 999] I
: / ..... \
: STOP :
: \ ..... /

```



```

/...../ \ TRUE
< IF(IOPT.EQ.2) GO TO 999 >-----0
\...../
I FALSE 7
I 7
I 7
/...../ 7
/ WRITE(1,702) / 7
/...../ 7
I 7
I---[702 FORMAT(' ENTER THE TWO-WAY ] 7
I [TRAVEL TIME THICKNESS IN 10THS ] 7
I [OF SECON *DS:') ] 7
I 7
I 7
/...../ 7
/ READ(1,*) T / 7
/...../ 7
I 7
I---[ BRANCH TO EXIT ] 7
I 7
I 7
..... 7
: T=T/20. : 7
:.....: 7
I 7
I---[ INPUT EXPERIMENTAL GEOMETRY ] 7
I [PARAMETERS ] 7
I 7
I 7
/...../ 7
/ WRITE(1,705) / 7
/...../ 7
I 7
I---[705 FORMAT(' ENTER THE WATER ] 7
I [DEPTH:') ] 7
I 7
I 7
/...../ 7
/ READ(1,*) ZB / 7
/...../ 7
I 7
I 7
/...../ 7
/ WRITE(1,706) / 7
/...../ 7
I 7
I---[706 FORMAT(' ENTER SOURCE DEPTH ] 7
I [AND RECEIVER DEPTH:') ] 7
I 7
I 7
/...../ 7
/ READ(1,*) ZS,ZR / 7
/...../ 7
I 7
I 7

```



/...../			2
/	WRITE(1,707)	/	2
/...../			7
	I		2
	I---[707 FORMAT(' ENTER SOUND SPEED ]		2
	I [AT SOURCE OR RECEIVER - ]		7
	I [WHICHEVER IS SH *ALLOWER:')		2
	I		2
	I		2
/...../			7
/	READ(1,*) CS	/	7
/...../			7
	I		2
	I		2
/...../			2
/	WRITE(1,708)	/	2
/...../			2
	I		2
	I---[708 FORMAT(' ENTER SOUND SPEED ]		7
	I [AT THE BOTTOM OF THE WATER:')		7
	I		7
	I		2
/...../			7
/	READ(1,*) C1	/	2
/...../			2
	I		2
	I---[ BRANCH TO INPUT OPTION ]		2
	I		7
	I		7
/...../		TRUE	2
< IF(IOPT.EQ.C) GO TO 500		>-----O	7
/...../			X 7
	I FALSE		X 2
	I		X 2
	I---[ INPUT INVERSION PARAMETERS ]		X 7
	I		X 7
	I		X 2
/...../			X 7
/	WRITE(1,709)	/	X 2
/...../			X 7
	I		X 2
	I---[709 FORMAT(' ATTENUATION ]		X 2
	I [CALCULATION',//, *' FOR A POINT ]		X 2
	I [BELOW THE CAUSTIC WHERE BL CURVE]		X 7
	I [IS NEARLY LINEAR,/' *,' ENTER A ]		X 7
	I [LOSS, FREQUENCY AND ANGLE: (ANG=]		X 7
	I [APPROX 20, FREQ = APPRO *X 200)']		X 7
	I		X 2
	I		X 7
/...../			X 7
/	READ(1,*) DBLOSS,FREQ,THETA	/	X 7
/...../			X 7
	I		X 7
	I		X 7

[illegible]

/...../			X	2
/	WRITE(1,713)	/	X	2
/...../			X	2
	I		X	2
	I---[713 FORMAT(' ENTER CANONICAL	]	X	2
	I [CURVE TYPE AND ATTENUATION	]	X	2
	I [PROFILE GRADIE *NT:')	]	X	2
	I		X	2
	I		X	2
/...../			X	2
/	READ(1,*) BETA,GAM	/	X	2
/...../			X	2
	I		X	2
	I		X	2
/...../			X	2
/	WRITE(1,714)	/	X	2
/...../			X	2
	I		X	2
	I---[714 FORMAT(' ENTER BASEMENT	]	X	2
	I [REFLECTION COEFFICIENT IN	]	X	2
	I [PRESSURE UNITS:')	]	X	2
	I		X	2
	I		X	2
/...../			X	2
/	READ(1,*)REF	/	X	2
/...../			X	2
	I		X	2
	I---[ OPTIONS AND ERROR CHECKING	]	X	2
	I		X	2
	I		X	2
/...../		FALSE	X	2
< IF(TIR.GT.D. .OR. RATIO .LE. D.)	>-----I		X	2
/...../			X	2
	I TRUE		X	2
	I		X	2
.....			X	2
: RATIO=1./COS(TIR*PI/180.)	:		X	2
.....			X	2
	I		X	2
	O<-----		X	2
	I		X	2
.....			X	2
: C2=C1*RATIO	:		X	2
: C3=C2	:		X	2
.....			X	2
	I		X	2
	I---[ IF GRADIENT G IS NOT SPECIFIED	]	X	2
	I [CALCULATE IT FROM THE	]	X	2
	I [ CAUSTIC ANGLE, THC	]	X	2
	I		X	2
	I		X	2





I			
I---	[ 141 FORMAT(□ DBLOSS=□,F8.2,□ ]	X	7
I	[ FREQ =□,F8.2,□ THETA =□,F8.2) ]	X	7
I		X	7
I		X	7
/	...../	X	7
/	WRITE(6,142) ALOSSD, ALOSSM, FM /	X	7
/	...../	X	7
I		X	7
I---	[ 142 FORMAT(□ ALOSSD=□,F8.2,□ ]	X	7
I	[ ALOSSM=□,F8.2,□ FM =□,F8.2) ]	X	7
I		X	7
I		X	7
/	...../	X	7
/	WRITE(6,143) TIR, THC, RATIO /	X	7
/	...../	X	7
I		X	7
I---	[ 143 FORMAT(□ TIR =□,F8.2,□ THC ]	X	7
I	[ □,F8.2,□ RATIO =□,F8.4) ]	X	7
I		X	7
I---	[ CHANGE DEGREES TO RADIANS ]	X	7
I		X	7
I		X	7
.....		X	7
:	THETA = THETA*PI/180. :	X	7
:	THC=THC*PI/180. :	X	7
:	TIR=TIR*PI/180. :	X	7
.....		X	7
I		X	7
I---	[ CALL ROUTINE WHICH CALCULATES ]	X	7
I	[ THE REMAINING ]	X	7
I	[ GEOPHYSICAL PARAMETERS FROM THE ]	X	7
I	[ INVERSION INPUTS ]	X	7
I		X	7
I		X	7
.....		X	7
:	CALL GEOPY :	X	7
.....		X	7
I		X	7
I		X	7
/	.....\	X	7
:	GO TO 499 :-----C	X	7
\	...../	U	7
I		U	7
I---	[ OPTIONAL BRANCH TO INPUT GEO- ]	U	7
I	[ PARAMETERS DIRECTLY ]	U	7
I		U	7
O<	-----O		7
[ 500]		U	7
.....		U	7
:	CONTINUE :	U	7
.....		U	7
I		U	7
I			



```

      I
      I
      /...../
      /
      WRITE(1,719)
      /...../
      I
      I---[719 FORMAT(' ENTER ATTENUATION   ]
      I   [PROFILE GRADIENT AND BASEMENT   ]
      I   [REFLECTIO *N COEFFICIENT IN     ]
      I   [PRESSURE:')]                     ]
      I
      I
      /...../
      /
      READ(1,*) GAM,REF
      /...../
      I
      I
      .....:
      :      C2=C1*RATIO
      :      C3=C2
      .....:
      I
      I---[ CALL A SUBROUTINE WHICH           ]
      I   [CALCULATES AND PRINTS VARIOUS     ]
      I   [ CRITICAL ANGLES CHARACTERISTIC   ]
      I   [OF THE MEASUREMENT                 ]
      I
      I
      O<-----O
      [ 499]
      I
      .....:
      :      CALL CANGLE
      :
      .....:
      I
      I---[ PRINT GEO-PARAMETERS             ]
      I
      I
      /...../
      /
      WRITE(6,145)
      /...../
      I
      I---[ 145 FORMAT(//,□ GEO-PARAMETERS ]
      I   [,//)                             ]
      I
      I
      /...../
      /
      WRITE(6,146)RATIO,PH2,PH3,D,G,RETA,
      /
      ALPHD,GAM,BZ,REF
      /...../
      I
      I---[ 146 FORMAT(□ RAT=□,F8.4,/ ,□ RH2]
      I   [□,F8.2,□ RH3=□,F8.2,/ , 1□ D =□, ]
      I   [F8.2,/ ,□ G =□,F8.2,□ BET=□,F8.2,]
      I   [, 2□ ALD=□,F9.3,□GAM=□,F11.5,/ ,□]
      I   [BZ =□,F8.2,□ REF=□,F8.2)         ]
      I
      I---[ CALL ROUTINES FOR FREQUENCY-     ]
      I   [INDEPENDENT INTERMEDIATE         ]
      I
      I

```

```

.....: Z
: : CALL REFL : : Z
: : .....: Z
: : I : Z
: : I : Z
.....: Z
: : CALL REFR : : Z
: : .....: Z
: : I : Z
: : I : Z
.....: Z
: : CALL BASE : : Z
: : .....: Z
: : I : Z
: : 0<-----0
[ 999] I
: /.....\
: RETURN :
: \...../

```



```

.....
\          SUBROUTINE GEOPY          /
\.....

      I
      I

.....
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
: ALPHO,CS,BZ,REF :
: COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71, :
: F71,DBLOSS,FREQ,THETA,ALOSSO,ALOSSM,FM, :
: TIR,THC,THRC,TH7B,BETA :
: :
: COMMON /ALPH/GAM :
: REAL LZERO,L70,L71 :
: DATA PI/3.141592655/ :
:.....

      I
      I---[OMPUTE DENSITIES RH2,RH3
      I
      I

.....
:          Z1=C1*RH1 :
:          D=C1/FM/4 :
:          R=EXP(-ALOG(10.)*ALOSSO/20) :
:          Z3=(1+R)/(1-R)*Z1 :
:          R=EXP(-ALOG(10.)*ALOSSM/20) :
:          Z2=(1+R)/(1-R)*Z1*Z3 :
:          Z2=SQRT(Z2) :
:          SPRAT=C3/C1 :
:          RH2=Z2/C2 :
:          RH3=Z3/C3 :
:.....

      I
      I---[OMPUTE DISSIPATION CONSTANT
      I      [ALPHO
      I
      I

```

```

:.....:
:      THETA=ACOS(C2/C1*COS(THETA))      :
:      BS=SIN(THETA)                     :
:      BC=COS(THETA)                     :
:      V32=(Z3-Z2)/(Z3+Z2)               :
:      V21=(Z2-Z1)/(Z2+Z1)               :
:      AUX=4*D*PI*FREQ/C1*SIN(THETA)      :
:      V=CABS((V21+V32*CMPLX(COS(AUX),SIN(AUX))) :
:      /(1+V21*V32*CMPLX(COS(AUX),SIN(AUX)))) :
:      T=CABS(1/(1+V21*V32*CMPLX(COS(AUX),SIN( :
:      AUX))))**2*16*Z1*Z3*(Z2/(Z1+Z2)/(Z2+Z3)) * :
:      *2 :
:      AUX=10.**(-DBLOSS/10.)-V**2 :
:      AUX=AUX/T :
:      ALS=-ALOG10(AUX)*10 :
:      FK=FREQ/1000 :
:      SIG=G*(1+BETA)*C2 :
:      AMU=(C2*(1+BETA))**2 :
:      ANU=BETA*C2 :
:      ALPHO=ALS/FK-2*C2/G/(1+BETA)/PC*(GAM*C2** :
:      2/2/SIG/BC**3*(BS-BS**3/3)+(BETA*GAM*C2** :
:      2+2*GAM*ANU*C2)/4/SIG/BC**2*(THETA+BS*BC) :
:      +(GAM*(ANU**2-AMU)+2*BETA*GAM*ANU*C2)/2/ :
:      SIG/BC*BS+BETA*GAM*(ANU**2-AMU)/2/SIG* :
:      THETA) :
:      ALPHO=ALPHO/(BS/BC+BETA*THETA)*G*(1+BETA) :
:      *BC/2/C2 :
:.....:
:
:      I
:      I
:      /-----\
:      RETURN
:      \-----/

```

```

.....
\          SUBROUTINE CANGLE          /
\.....
      I
      I
.....
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
: ALPHO,CS,BZ,REF                          :
:      COMMON /ALPH/GAM                     :
:      COMMON /T/T                         :
:.....
      I
      I
.....
: COMMON /DATA/ LZERO,FZERO,L70,F70,TH70, :
: L71,F71,DBLOSS,FREQ,THETA,ALOSSO,ALOSSM, :
: FM,TIR,THC,THRC,TH1B,BETA               :
:.....
      I
      I
.....
:      REAL LZERO,L70,L71                  :
:.....
      I
      I
.....
:      DATA FI/3.14159264/                :
:.....
      I
      I
.....
:      DI=2.*ZB-ZR-ZS                      :
:.....
      I
      I---[ CALCULATE SEDIMENT THICKNESS ]
      I
      I
.....
:      B=BETA                              :
:      CZP=2000                            :
:      A=C2*(G*(1.+B)*T+1.+B*ALOG(C2))    :
:.....
      I
      I
      0<-----0
[ 60]      I                                Z
.....                                Z
: CZ=CZP+(A-CZP-B*C2*ALOG(C7P))/(1.+B*C2/ :
: CZP)                                     :
:.....                                Z
      I                                Z
      I                                Z
.....                                Z
/-----\ TRUE
< IF (ABS(CZ-CZP).LT..01) GO TO 70 >-----0
\-----/                                X Z
      I FALSE                            X Z
      I                                X Z
      I                                X Z

```

```

.....X Z
: CZP=CZ X Z
:.....X Z
I X Z
I X Z
/.....X Z
: GO TO 60 :-----0
\.....X
X
X
0<-----0

[ 70] I
.....
: BZ=((CZ+B*C2)**2-C2**2*(1+B)**2)/(2*G*(1+ :
: B)*C2) :
:.....:
I
I---[ COMPUTE REFINED CRITICAL ANGLE ]
I
I
.....
: THRC=P1/4 :
:.....:
I
I
.....
: : CALL TOTCI : :
:.....:
I
I---[ COMPUTE CRITICAL RAY DEPTH CRD ]
I
I
.....
: CAUX=C1/COS(THRC) :
: CRD=((CAUX+BETA*C3)**2-(C3*(1+BETA))**2) :
: /2/G/(1+BETA)/C3 :
:.....:
I
I---[ CALCULATE VELOCITY, VELOCITY ]
I [GRADIENT, AND ATTENUATION ]
I [ CONSTANT AT DEPTH OF 500 METERS]
I
I
.....
: RSPD=SQRT(2*G*(1+BETA)*C3*500+C3**2*(1+ :
: BETA)**2)-BETA*C3 :
: PGRAD=G*(1+BETA)/(RSPD/C3+BETA) :
: ALBOT=ALPHO+GAM*500 :
:.....:
I
I---[ COMPUTE TWO WAY TRAVEL TIME IN ]
I [SECONDS ]
I
I

```

```

.....
:          TWTT=2*T          :
:          SPRAT=C2/C1       :
:.....
:          I
:          I---[ COMPUTE BASEMENT CRITICAL
:          I    ANGLES TH1B,TH3B
:          I
:          I
:.....
: CB=SQRT(2*G*(1+BETA)*C3*BZ+C3**2*(1+BETA) :
: **2)-BETA*C3                :
:          TH1B=ACOS(C1/CB)    :
:          TH3B=ACOS(C3/CB)    :
:          R=DI/TAN(TH1B)+2*C3*TAN(TH3B)/G*(BETA/( :
:          1+BETA))*(1+(1+TH3B/SIN(TH3B)/COS(TH3B))/ :
:          2/BETA)             :
:.....
:          I
:          I---[ COMPUTE SMALLEST APPARENT ANGLE]
:          I    [FOR BASEMENT REFLECTION
:          I
:          I
:.....
:          THP=ATAN(DI/R)      :
:.....
:          I
:          I---[ CHANGE RADIAN TO DEGREE
:          I
:          I
:.....
:          THP=THP*180/PI
:          A=TIR*180/PI
:          A1=THC*180/PI
:          A2=THRC*180/PI
:          A3=TH1R*180/PI
:.....
:          I
:          I---[ PRINT OUT CRITICAL ANGLES
:          I
:          I
:          /-----/
:          /          WRITE(6,1)          /
:          /-----/
:          I
:          I---[ 1 FORMAT(1X,/, , CRITICAL
:          I    [ANGLE=,/)
:          I
:          I
:          /-----/
:          /          WRITE(6,11)A,SPRAT,A1,A2,THB,A3,TWTT,/
:          /          BZ,CRD,BGRAD,BSPD,ALEOT,GAM
:          /-----/

```



[ 999 ]

129

```

.....
\      SUBROUTINE TOTCI      /
\...../

      I
      I

.....
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
: ALPHD,CS,BZ,REF           :
: COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71, :
: F71,DBLOSS,FREQ,THETA,ALOSS0,ALOSSM,FM,   :
: TIR,THC,THRC,TH1B,BETA    :
:          REAL LZERO,L70,L71               :
:.....

      I
      I---[ CHECK THAT C3 LESS THAN C2       ]
      I
      I
      I
/-----\ TRUE
< IF(C3.LE.C2)GO TO 10 >-----0
\...../
      I FALSE
      I
      I
      I
/-----\
/ WRITE(1,11) \
/...../
      I
      I---[ 11 FORMAT(" C3 MUST BE LESS     ]
      I [THAN OR EQUAL TO C2")             ]
      I
      I
      I
/-----\
: STOP :
\...../

O<-----0

[ 10]      I
.....
: PI=3.141592654 :
:.....
      I
      I---[ COMPUTE TIR=ANGLE OF TOTAL       ]
      I [INTERNAL REFLECTION                 ]
      I
      I
.....
: TIR=0 :
:.....
      I
      I

```



```

A .....
A : THRC=AUX :
A : TH3=ACOS(FAC*COS(THRC)) :
A : RAUX=D1/TAN(THRC)+D2*TAN(TH3)*(1+(1+TH3/ :
A : SIN(TH3)/COS(TH3))/2/BETA) :
A .....
A I
A I
A /.....\ TRUE
A < IF(RAUX.GT.R)GO TO 500 >-----V
A \...../
A I FALSE
A I
A I
A .....
A : R=RAUX :
A .....
A I
A I
A /.....\
A : GO TO 200 :-----O
A \...../ X
A X
A X
A O<-----O
A [ 500] I X
A ..... X
A : R=RAUX : X
A : DELT=-DELT/3 : X
A ..... X
A I X
A I X
A /.....\ TRUE
A < IF(ABS(DELT).LE.1.E-6) GO TO 999 >-----O
A \...../ X
A I FALSE X
A I X
A O<-----O
A [ 200] I
A .....
A : CONTINUE :
A .....
A I
A I
A /.....\
A : WRITE(1,1) :
A /...../
A I
A I---[ 1 FORMAT(= CRITICAL ANGLE ]
A I [FAILED TO CONVERGE=) ]
A I
A I
A /.....\
A : STOP :
A \...../

```

```

I---[ BOTTOM ANGLE OF REFRACTED RAY ] Z
I  [AT CRITICAL ANGLE ] Z
I Z
0<-----0

```

[ 999]

I

```

.....:
:      THC=ATAN(D1/R)      :
: CB=SQRT(2*G*(1+BETA)*C3*BZ+(C3*(1+BETA))* :
: *2)-BETA*C3             :
:      TH1B=ACOS(C1/CB)    :
:.....:

```

I

I

```

/.....\
:      RETURN      :
\...../

```



```

.....
\          SUBROUTINE REFL          /
\.....
      I
      I
.....
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
: ALPH0,CS,BZ,REF :
: COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71, :
: F71,DBLOSS,FREQ,THETA,ALOSSD,ALOSSM,FM, :
: TIR,THC,THRC,TH1B,BETA :
:      REAL LZERO,L70,L71 :
: COMMON /R/NSAP,RV21,RV32,RSIN2,RDTS,RDTR, :
: RT,RGI :
: DIMENSION RV21(90),RV32(90),RSIN2(90), :
: RDTS(90),RDTR(90),RT(90),RGI(90) :
:.....
      I
      I---[*****]
      I [*****]
      I [***]
      I [ RETURNS IN COMMON]
      I [ NSAP=NSAP=SMALLEST ANGLE(DEG)]
      I [ TO REACH SURFACE DUE TO SOUND]
      I [ PROFILE]
      I [ RV21,RV32=REFLECTION COEFFICIEN]
      I [ S FOR RESPECTIVE INTERFACE]
      I [ RSIN2=SIN OF GRAZING ANGLE IN]
      I [ HIGH SPEED LAYER]
      I [ RDTS,RDTR=REFLECTION PATH DELTA]
      I [ T FOR SOURCE,RECEIVER RESP.]
      I [ RT=TRAVEL TIME FOR REFLECTION]
      I [ PATH]
      I [ RGI=GEOMETRIC INTENSITY OF]
      I [ REFLECTION PATH]
      I [*****]
      I [*****]
      I [***]
      I [ COMPUTE NSAP]
      I
      I
.....
:      PI=3.141592654 :
:      NSAP=1 :
:.....
      I
      I
      /-----\
< IF(C1.GE.CS)GO TO 100 >-----0
\...../ Z
      I FALSE Z
      I Z
      I Z
      I Z

```

```

.....
:      SAP=ACOS(C1/CS)*180/PI      :
:      NSAP=SAP+1                  :
.....
I
I
/-----/
/      WRITE(1,1) SAP      /
/-----/
I
I---[ 1 FORMAT(= SMALLEST ANGLE TO ]
I   [REACH SURFACE=,F8.2)         ]
I
I<-----0
[ 100]
I
.....
:      CONTINUE                  :
.....
I
I---[ COMPUTE REFLECTION COEFFICIENTS]
I   [FOR ANGLES GREATER THAN TIR,SAP ]
I
I
.....
:      NTIR=TIR*180/PI+1          :
:      N=MAX0(NTIR,NSAP)          :
:      Z1=RH1*C1                  :
:      Z2=RH2*C2                  :
:      Z3=RH3*C3                  :
:      DELT=PI/180                :
:      TH=(NSAP-1)*DELT           :
:      FAC2=C2/C1                 :
:      FAC3=C3/C1                 :
:      FACS=CS/C1                 :
:      AR=2*ZR/CS                 :
:      AS=2*ZS/CS                 :
:      D1=2*ZB-ZR-ZS              :
.....
I
I
A-->:      DO 200 I=NSAP,90      :
A   :
A   I
A   I
A   :
A   :      TH=TH+DELT              :
A   :      CTH=COS(TH)             :
A   :
A   I
A   I---[ SURFACE SCATTERING TRAVEL TIME ]
A   I   [DIFFERENCES               ]
A   I
A   I

```

```

A .....:
A :      S=SQRT(1-(FACS*CTH)**2)      :
A :      ROTS(I)=AS*S                 :
A :      RDTR(I)=AR*S                 :
A .....:
A      I
A      I
A /-----\ TRUE
A <      IF(I.LT.N)GO TO 200          >-----0
A \-----/
A      I FALSE
A      I
A      I---[ SIN2 ]
A      I
A      I
A .....:
A :      PSIN2(I)=SQRT(1-(FAC2*CTH)**2) :
A .....:
A      I
A      I---[ REFLECTION COEFFICIENTS ]
A      I
A      I
A .....:
A :      A1=Z1/SIN(TH)                 :
A :      A2=Z2/RSIN2(I)                :
A :      A3=Z3/SQRT(1-(FAC3*CTH)**2)   :
A :      RV32(I)=(A3-A2)/(A3+A2)       :
A :      RV21(I)=(A2-A1)/(A2+A1)       :
A .....:
A      I
A      I---[ TRAVEL TIME ]
A      I
A      I
A .....:
A :      R=D1/TAN(TH)                  :
A :      RT(I)=R/(CTH*C1)              :
A .....:
A      I
A      I---[ GEOMETRIC INTENSITY(AMPLITUDE) ]
A      I
A      I
A .....:
A :      RGI(I)=CTH/R                  :
A .....:
A      I
A      0<-----0
A [ 200 ]
A .....:
A ---:      CONTINUE
A .....:
A      I
A      I
A /-----\
A :      RETURN
A \-----/

```

```

.....
\ SUBROUTINE REFR /
\ .....

```

```

I
I

```

```

.....
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
: ALPHO,CS,BZ,REF :
: COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71, :
: F71,DBLOSS,FREQ,THETA,ALOSS0,ALOSSM,FM, :
: TIR,THC,THRC,TH1B,BETA :
: :
: COMMON /ALPH/GAM :
: :
: REAL LZERO,L70,L71 :
: COMMON /B/BV21,BV32,BSIN2,BTRF,BGI,BLS, :
: BT,BDTS,BDTR :
: COMMON /S/SV21,SV32,SSIN2,STRF,SGI,SLS, :
: ST,SDTS,SDTR :
: DIMENSION BV21(90),BV32(90),BSIN2(90), :
: BTRF(90),BGI(90),BLS(90),BT(90),BDTS(90), :
: BDTR(90) :
: DIMENSION SV21(90),SV32(90),SSIN2(90), :
: STRF(90),SGI(90),SLS(90),ST(90),SDTS(90), :
: SDTR(90) :
: :
: :
.....

```

```

I
I---[*****]
I [*****]
I [***]
I [ FOR EACH SPECULAR BOTTOM ANGLE ]
I [BETWEEN THE ANGLE OF TOTAL ]
I [INTERNAL ]
I [ REFLECTION AND THE CRITICAL ]
I [ANGLE THIS SUBROUTINE RETURNS ]
I [ (SMALL BOTTOM ANGLE PREFIX S, ]
I [BIG BOTTOM ANGLE PREFIX B) ]
I [ V21,V32=REFLECTION COEFFICIENTS]
I [AT INTERFACE ]
I [ SIN2=SIN OF GRAZING ANGLE IN ]
I [HIGH SPEED LAYER ]
I [ TRF=TRANSMISSION COEFFICIENT ]
I [FACTOR ]
I [ GI=GEOMETRIC INTENSITY ]
I [ LS=ARC LENGTH OF RAY IN THE ]
I [BOTTOM ]
I [ T=TRAVEL TIME ]
I [ DTS,DTR=DELTA T FOR SURFACE ]
I [REFLECTION FOR SOURCE,RECEIVER ]
I [RESP. ]
I [*****]
I [*****]
I [***]
I
I

```

```

.....
:      PI=3.141592654
:      NTIR=TIR*180/PI+1
:      NTHC=THC*180/PI+1
:      N=NTHC-NTIR
:      DEL=PI/180
:      TH=(NTHC-1)*DEL
:      Z1=RH1*C1
:      Z2=RH2*C2
:      Z3=RH3*C3
:      FAC2=C2/C1
:      FAC3=C3/C1
:      FACS=CS/C1
:      SEST=THRC
:      BEST=THRC
:      D1=2*ZR-ZR-ZS
:      D2=2*C3**2/G/C1
:      D3=2*C3/G*BETA/(1+BETA)
:      D4=BETA/(1+BETA)/G
:      D7=1+BETA
:      D5=D1/C1
:      D6=2/CS
:      ANU=BETA*C3
:      SIG=G*(1+BETA)*C3
:      AMU=C3**2*(1+BETA)**2
:      D8=2*C3/G/(1+BETA)/ALPHO
:      D9=-GAM*C3**2/SIG/6
:      D10=(BETA*GAM*C3**2+GAM*ANU*C3*2)/4/SIG
:      D11=-3*D9
:      D12=(GAM*(ANU**2-AMU)+2*ALPHO*SIG+2*BETA*
:      ANU*C3*GAM)/2/SIG
:      D14=BETA*GAM*(ANU**2-AMU)/2/SIG+BETA*
:      ALPHO
:
.....

```

```

:      I
:      I
:
.....
A----->:      DO 10 I=1,90
:
:      I
:      I
:
.....
:      BTRF(I)=0
:
:      I
:      I
:      [ 10]
:
.....
A----->:      STRF(I)=0
:
:      I
:      I

```



```

A-->: ..... DO 100 I=1,N .....
A: .....
A: I
A: I
A: .....
A: J=NTHC-I .....
A: R=D1/TAN(TH) .....
A: .....
A: I
A: I
A: .....
A: : CALL REFRN(TH,SEST,BEST,SA,SA3,BA, : :
A: : BA3) : :
A: : .....
A: I
A: I
A: / ..... \ TRUE
A: < IF(BA.GT.TH1B)GO TO 998 >-----0
A: \ ..... /
A: I FALSE
A: I
A: I
A: .....
A: : BC1=COS(BA) .....
A: : BS1=SQRT(1-BC1**2) .....
A: : BC2=FAC2*BC1 .....
A: : BS2=SQRT(1-BC2**2) .....
A: : BC3=FAC3*BC1 .....
A: : BS3=SQRT(1-BC3**2) .....
A: : .....
A: I
A: I---[ BIG ANGLE REFLECTION COEFFICIEN]
A: I
A: I
A: .....
A: : A1=Z1/BS1 .....
A: : A2=Z2/BS2 .....
A: : A3=Z3/BS3 .....
A: : BV32(J)=(A3-A2)/(A3+A2) .....
A: : BV21(J)=(A2-A1)/(A2+A1) .....
A: : BTRF(J)=16*A1*A3*(A2/(A3+A2)/(A2+A1))**2 .....
A: : BSIN2(J)=BS2 .....
A: : .....
A: I
A: I---[ GEOMETRIC AMPLITUDE ]
A: I
A: I
A: .....
A: : DRDT=-D1/BS1**2+D2*(BS1/BS3/BC3**2)*(1.+ :
A: : BA3*TAN(BA3)/D7) :
A: : EGI(J)=BC1/(R*BS1*ABS(DRDT)) :
A: : EGI(J)=SQRT(EGI(J)) :
A: : .....

```







.....  
SUBROUTINE BASE  
.....

```

I
I---[*****]
I  [*****]
I  [***]
I  [ FOR EACH SPECULAR BOTTOM ANGLE ]
I  [SUB RETURNS]
I  [ BSV21,BSV32=REFLECTION]
I  [COEFFICIENTS AT INTERFACE]
I  [ BSSIN2=SIN OF GRAZING ANGLE IN ]
I  [HIGH SPEED LAYER]
I  [ BSTRF=TRANSMISSION COEFFICIENT ]
I  [FACTOR]
I  [ BSGI=GEOMETRIC AMPLITUDE]
I  [ BSLS=ARC LENGTH OF RAY IN]
I  [BOTTOM]
I  [ BST=TRAVEL TIME]
I  [ BSDTS,BSDTR=DELTA T FOR SURFACE]
I  [REFLECTION FOR SOURCE RECEIVER ]
I  [*****]
I  [*****]
I  [***]
I
I
I

```

```

: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,PH2,RH3,G,D, :
: ALPH0,CS,BZ,REF :
: COMMON /DATA/LZERO,FZERO,L70,F70,TH70, :
: L71,F71,DELOSS,FREQ,THETA,ALOSS0,ALOSSM, :
: FM,TIR,THC,THRC,TH1B,BETA :
: COMMON /BS/BSV21,BSV32,BSSIN2,BSTRF,BSGI, :
: BSLS,BST,BSDTS,BSDTR :
: DIMENSION BSV21(90),BSV32(90),BSSIN2(90), :
: BSTRF(90),BSGI(90),BSLS(90),BST(90), :
: BSDTS(90),BSDTR(90) :
: :
: COMMON /ALPH/GAM :
: :
: REAL LZERO,L70,L71 :
: :
: PI=3.141592654 :
: :
: NTIR=TIR*180/PI+1 :
: :
: DEL=PI/180 :
: :
: TH=PI/2 :
: :
: Z1=RH1*C1 :
: :
: Z2=RH2*C2 :
: :
: Z3=RH3*C3 :
: :
: FAC2=C2/C1 :
: :
: FAC3=C3/C1 :
: :
: FACS=CS/C1 :
: :
: CR=SQRT(2*G*(1+BETA)*C3*BZ+(C3*(1+BETA))* :
: *2)-BETA*C3 :
: :
: :
: FACR=CB/C1 :
: :
: D1=2*ZR-ZR-ZS :
: :
: D2=2*C3**2/C1/G/(1+BETA) :
: :
: D3=2*C3/G/(1+BETA) :
: :
: D4=2/G/(1+BETA) :
: :
: D5=D1/C1 :
: :
: D6=2/CS :
: :
: D7=2*C3*BETA/G/(1+BETA)/C1 :
: :
: .....

```





```

A .....
A : :      CALL PASANG(TH,BSA,BSA3)      : :
A .....
A      I
A      I
A /-----\ TRUE
A < IF(BSA3.EQ.0.0) GO TO 100 >-----0
A \-----/
A      I FALSE
A      I
A      I
A .....
A :      BC1=COS(BSA) :
A :      BS1=SQRT(1-BC1**2) :
A :      BC2=FAC2*BC1 :
A :      BS2=SQRT(1-BC2**2) :
A :      BC3=FAC3*BC1 :
A :      BS3=SQRT(1-BC3**2) :
A :      BCB=FACB*BC1 :
A :      BSP=SQRT(1-BCB**2) :
A .....
A      I
A      I---[ DELTA T SOURCE RECEIVER ]
A      I
A      I
A .....
A :      AUX=FACS*BC1 :
A .....
A      I
A      I---[ IF RAY DOES NOT REACH SURFACE ]
A      I [NOT COMPUTED ]
A      I
A      I
A /-----\ TRUE
A < IF(AUX.GT.1.) GO TO 999 >-----0
A \-----/
A      I FALSE
A      I
A      I
A .....
A :      SS=SQRT(1-AUX**2) :
A :      BSDTR(J)=D6*ZR*SS :
A :      BSDTS(J)=D6*ZS*SS :
A .....
A      I
A      I---[ LAYER REFLECTION COEFFICIENTS ]
A      I
A      I
A .....
A :      A1=Z1/BS1 :
A :      A2=Z2/BS2 :
A :      A3=Z3/BS3 :
A :      BSV32(J)=(A3-A2)/(A3+A2) :
A :      BSV21(J)=(A2-A1)/(A2+A1) :
A :      BSTRF(J)=16*A1*A3*(A2/(A3+A2)/(A2+A1))** :
A : 2 :
A :      ESSIN2(J)=BS2 :
A .....

```

```

A                                     I
A                                     I---[ GEOMETRIC AMPLITUDE ]
A                                     I
A                                     I
A .....
A :                               BSAB=ACOS(BCB)                               :
A .....
A                                     I
A                                     I---[ FOLLOWING 4 CARDS ADDED 5/59/79 ]
A                                     I
A                                     I
A .....
A : DRDT3=DA*(BS3/BC3**3*(BSA3-BSAB+BS3*BC3- :
A : BSB*BCB)+(1.-(CB/C3)**3*BS3/BSB))+DB/BC3* :
A : (1./BC3-BS3*(BSB/BC3+(CB/C3)**2*BC3/BSB)) :
A : DRDT=-D1/BS1**2+(C3/C1)*BS1/BS3*DRDT3 :
A : R=D1/TAN(TH) :
A : BSGI(J)=PC1/(R*BS1*ABS(DRDT)) :
A : BSGI(J)=SQRT(BSGI(J)) :
A .....
A                                     I
A                                     I---[ ARC LENGTH ]
A                                     I
A                                     I
A .....
A : BSLS(J)=DE/PC3*(D9/PC3**3*(BS3**3-BSB**3) :
A : +D10/PC3**2*(ES3*BC3-BSB*BCB)+(D11/PC3** :
A : 3+D12/BC3)*(BS3-BSB)+(D10/BC3**2+D14)*( :
A : BSA3-BSAB)) :
A .....
A                                     I
A                                     I---[ TRAVEL TIME ]
A                                     I
A                                     I
A .....
A : BST(J)=D5/BS1+D4*((BSA3-BSAB)/BC3+BETA* :
A : ALOG((1+BS3)/(1-BS3)*(1-BSB)/(1+BSB))/2) :
A .....
A                                     I
A                                     O<-----O
A [ 100 ]                                     I
A .....
A -----: CONTINUE :
A .....
A                                     I
A                                     O<-----O
A [ 999 ]                                     I
A                                     / ..... \
A : RETURN :
A                                     \ ..... /

```

```

.....
\ SUBROUTINE REFRN(TH,SEST,BEST,SA,SA3, /
\ BA,BA3) /
\ ...../

I
I

.....
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
: ALPHO,CS,EZ,REF :
: COMMON /DATA/LZERO,FZERO,L70,F70,TH70, :
: L71,F71,DBLOSS,FREQ,THETA,ALOSSO,ALOSSM, :
: FM,TIR,THC,THPC,TH1B,BETA :
: REAL LZEPO,L70,L71 :
: .....:

I
I---[*****]
I [*****]
I [***] ]
I [ GIVEN ]
I [ TIR=ANGLE OF TOTAL INTERNAL ]
I [ REFLECTION ]
I [ TH=GRAZING ANGLE ]
I [ SEST=ESTIMATE SMALL ANGLE ]
I [ BEST=ESTIMATE BIG ANGLE ]
I [ RETURNS ]
I [ SA=SMALL ANGLE REFRACTED RAY ]
I [ BA=BIG ANGLE REFRACTED RAY ]
I [*****]
I [*****]
I [***] ]
I
I
I
/.....\ TRUE
< IF(TH.GT.TIR)GO TO 100 >-----0
\ ...../ 2
I FALSE 2
I 2
I 7
/...../ 2
/ WRITE(1,1) / 2
/...../ 2
I 2
I---[ 1 FORMAT(= SPECULAR ANGLE OF ] 2
I [ REFRACTED RAY LESS THAN TIR=) ] 2
I 2
I 2
/.....\ 2
: STOP : 2
\ ...../ 2
2
0<-----0
I
[ 100]

```

```

.....
:      D1=2*ZB-ZR-ZS
:      PI2=3.141592654
:      PI2=PI2/2
:      D2=2*C3/G*(BETA/(1+BETA))
:      D3=1/(2*BETA)
:      FAC3=C3/C1
:      R=D1/TAN(TH)
:      T3=ACOS(FAC3*COS(SEST))
: VAL =D1/TAN(SEST)+D2*TAN(T3)*(1+(1+T3/
: SIN(T3)/COS(T3))*D3)-R
:      DEL=(SEST-TIR)/10.0001
:
.....

```

I

I---[ COMPUTE SA

]

I

[ 102]

I

```

.....
:      DO 200 I=1,500
:
.....

```

I

I

```

/.....\
< IF(ABS(DEL).LT.1.E-6) GO TO 201 >
\...../

```

TRUE

I FALSE

I

I

```

.....
:      SA=SEST-DEL
:
.....

```

I

I

```

/.....\
< IF(SA.LE.TIR)GO TO 211 >
\...../

```

TRUE

I FALSE

I

I

```

/.....\
< IF(SA.GE.THPC)GO TO 211 >
\...../

```

TRUE

I FALSE

I

I

```

.....
:      T3=ACOS(FAC3*COS(SA))
: VALP=D1/TAN(SA)+D2*TAN(T3)*(1+(1+T3/SIN(
: T3)/COS(T3))*D3)-R
:      AUX=VAL*VALP
:      SEST=SA
:      VAL=VALP
:
.....

```

I

I



A	/	TRUE	X	7
A	<	IF(AUX.GT.0.)GO TO 200	X	7
A	/	...../	X	7
A		I FALSE	U	7
A		I	U	7
A	[ 210]	I	U	7
A	.....		U	7
A	:	DEL=-DEL/3	U	7
A	:	.....	U	7
A		I	U	7
A		I	U	7
A	/	...../	U	7
A	:	GO TO 200	V	7
A	:	.....	U	7
A			U	7
A		0<-----	U	7
A	[ 211]	I	U	7
A	.....		U	7
A	:	DEL=DEL/3	U	7
A	:	.....	U	7
A		I	U	7
A		0<-----	U	7
A	[ 200]	I		7
A	.....			7
A	-----:	CONTINUE		7
A	:	.....		7
A		I		7
A		I		7
A	/	...../		7
A	/	WRITE(1,2)		7
A	/	...../		7
A		I		7
A		I---[ 2 FORMAT(□ SMALL BOTTOM	]	7
A		I [REFRACTION ANGLE DOES NOT	]	7
A		I [CONVERGE□)	]	7
A		I		7
A		I		7
A	/	...../		7
A	:	STOP		7
A	:	.....		7
A				7
A		0<-----		7
A	[ 201]	I		7
A	.....			7
A	:	SA3=T3		7
A	:	.....		7
A		I		7
A		I---[ BA INITIALIZATION	]	7
A		I		7
A		I		7







I TRUE  
I

1  
0 < -----

.....  
I FALSE

```

I---[ COMPUTE BSA
I

```

[ 102 ]

.....  
DO 200 1=1-500

.....

A →  
A  
A  
A







```

.....
\          SUBROUTINE LOSS(JJ)          /
\...../
      I
      I
.....
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
: ALPH9,CS,BZ,REF :
: COMMON /DATA/LZERO,FZERO,L70,F70,TH70, :
: L71,F71,DBLOSS,FREQ,THETA,ALOSS0,ALOSSM, :
: FM,TIR,THC,THRC,TH1P,BETA :
: COMMON/AL/F(6),ALOSS(6,90) :
: COMMON /R/NSAP,RV21,RV32,RSIN2,RDTS,RDTR, :
: RT,RGI :
: DIMENSION RV21(90),PV32(90),RSIN2(90), :
: RDTS(90),RDTR(90),RT(90),RGI(90) :
: COMMON /B/BV21,BV32,BSIN2,BTRF,BGI,BLS, :
: BT,BDTS,BDTR :
: COMMON /S/SV21,SV32,SSIN2,STRF,SGI,SLS, :
: ST,SDTS,SDTR :
: DIMENSION BV21(90),BV32(90),BSIN2(90), :
: BTRF(90),BGI(90),BLS(90),BT(90),BDTS(90), :
: BDTR(90) :
: DIMENSION SV21(90),SV32(90),SSIN2(90), :
: STRF(90),SGI(90),SLS(90),ST(90),SDTS(90), :
: SDTR(90) :
: COMMON /BS/PSV21,BSV32,BSSIN2,BSTRF,BSGI, :
: BSLS,BST,BSDTS,BSDTR :
: DIMENSION BSV21(90),BSV32(90),BSSIN2(90), :
: BSTRF(90),BSGI(90),BSLS(90),BST(90), :
: BSDTS(90),BSDTR(90) :
: COMPLEX AUX99,V,AIM,AUX1,AR(16),PH(16) :
: DIMENSION BR(4) :
: REAL LZERO,L70,L71 :
.....
      I
      I---[*****]
      I [*****]
      I [***]
      I [ THIS SUBROUTINE COMPUTES ]
      I [ APPARENT LOSS DUE TO PROPAGATION ]
      I [*****]
      I [*****]
      I [***]
      I
      I

```

```

.....
:      PI=3.141592654
:      ALPH0=ALOG(10.)/4/PI/10000*ALPH9
:      EX=ALOG10(EXP(1.))
:      PI2=2*PI
:      AIM=CMPLX(0.,1.)
:      SQRT2=SQRT(2.)
:      F1=F(JJ)/SQRT2
:      F2=F(JJ)*SQRT2
:      FPI2D=4.*PI*F(JJ)*D/C2
:      NAV1=8
:      FPIINC = FPI2D*(SQRT2-1.0/SQRT2)/NAV1
:      FPIIN=FPI2D-(NAV1-1)*FPIINC/2.
:      NTHC=THC*180/PI
:      N=90-NTHC
.....

```

```

I
I---[ COMPUTE LOSS FOR ANGLES ABOVE
I   [CRITICAL (CAUSTIC)
I
I

```

```

A----->:      DO 10 I=1,90
A
A
A      I
A      [ 10]      I
A-----:      ALOSS(JJ,I)=25.
A
A

```

```

A----->:      DO 100 I=1,N
A
A
A      I
A      I
A
A      J=91-I
A      FPIAUX=FPIIN
A      AUX=0.
A
A      I
A      I

```

```

A B----->:      DO 20 NAV=1,NAV1
A B
A B
A B      I
A B      I
A B
A B      ALPH2=FPIAUX*NAV*SIN2(J)
A B      C=COS(ALPH2)
A B      S=SIN(ALPH2)
A B      VV=(RV21(J)+RV32(J)*C)**2+(RV32(J)*S)**2
A B      VV=VV/((1+RV21(J)*RV32(J)*C)**2+(RV21(J)*
A B      RV32(J)*S)**2)
A B      AUX=AUX+VV
A B      FPIAUX=FPIAUX+FPIINC
A B
A B

```





```

A B .....: Z
A B : NA=K+1 : Z
A B .....: Z
A B I : Z
A B I : Z
A B .....: Z
A B C-->: DO 110 L=NA,4 : Z
A B C : .....: Z
A B C I : Z
A B C I : Z
A B C .....: Z
A B C : AUX=BR(K)*BR(L) : Z
A B C : AUX1=(PH(K)-CONJG(PH(L)))*AIM : Z
A B C : .....: Z
A B C I : Z
A B C I : Z
A B C / ..... \ TRUE : Z
A B C < IF(REAL(AUX1)*F2.LT.-40.)GO TO 110 >-----0 : Z
A B C \ ..... / X : Z
A B C I FALSE X : Z
A B C I X : Z
A B C I X : Z
A B C ..... X : Z
A B C : V=V+AUX*(CEXP(F2*AUX1)-CEXP(F1*AUX1))/ : X : Z
A B C : AUX1 : X : Z
A B C : ..... X : Z
A B C I X : Z
A B C 0<-----0 : Z
A B C [ 110] I : Z
A B C .....: Z
A -----: CONTINUE : Z
A : .....: Z
A I : Z
A I : Z
A .....: Z
A : AUX=2*REAL(V) : Z
A : AUX2=-2*PI2*ALPH0*BSLS(J) : Z
A : .....: Z
A I : Z
A I : Z
A / ..... \ TRUE : Z
A < IF(AUX2*F2.LT.-40.)GO TO 120 >-----V : Z
A \ ..... / : Z
A I FALSE : Z
A I : Z
A I : Z
A .....: Z
A : AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/ : Z
A : AUX2*PF(1)**2 : Z
A : .....: Z
A I : Z
A 0<-----0 : Z
A [ 120] I : Z

```

```

A .....
A : DT=DT+AUX/(2*RG1(J))*2/F1 :
A : ALOSS(JJ,J)=-10.*ALOG10(DT) :
A .....
A I
A [ 100] I
A .....
A : CONTINUE :
A .....
A I
A I
A .....
A : NMAX=91-N :
A .....
A I
A I---[ COMPUTE LOSS FOR ANGLES BETWEEN]
A I [TIR AND THS ]
A I
A I
A .....
A : NTIR=TIR*180/PI+1 :
A : N=NMAX-NTIR :
A .....
A I
A I
A .....
A : DO 200 I=1,N :
A .....
A I
A I
A .....
A : J=NMAX-I :
A .....
A I
A I
A /-----\ TRUE
A < IF(J.LT.NSAP)GO TO 800 >-----C
A \-----/
A I FALSE
A I
A I---[ COMPUTE REFLECTION COEFFICIENT ]
A I
A I---[COMPUTE FREQ AVERAGE ABSOLUTE ]
A I [REFLECTION ]
A I
A I
A .....
A : FPIAUX=FPIIN :
A : AUX=0 :
A .....
A I
A I
A .....
A B--> : DO 130 NAV=1,NAV1 :
A B :

```

A	B	I	7
A	B	I	7
A	B	.....	7
A	B	: ALPH2=FPIAUX*RSIN2(J)	7
A	B	: C=COS(ALPH2)	7
A	B	: S=SIN(ALPH2)	7
A	B	: VV=(RV21(J)+RV32(J)*C)**2+(RV32(J)*S)**2	7
A	B	: VV=VV/((1+RV21(J)*RV32(J)*C)**2+(RV21(J)*	7
A	B	: RV32(J)*S)**2)	7
A	B	: AUX=AUX+VV	7
A	B	: FPIAUX=FPIAUX+FPIINC	7
A	B	.....	7
A	B	I	7
A	B	[ 130] I	7
A	B	.....	7
A	B	---: CONTINUE	7
A	B	.....	7
A	B	I	7
A	B	I	7
A	B	.....	7
A	B	: VV=AUX/NAV1	7
A	B	: ALPH2=FPI2D*RSIN2(J)	7
A	B	: C=COS(ALPH2)	7
A	B	: S=SIN(ALPH2)	7
A	B	: V=CMPLX(RV21(J)+RV32(J)*C,RV32(J)*S)	7
A	B	: V=V/CMPLX(1+RV21(J)*RV32(J)*C,RV21(J)*	7
A	B	: RV32(J)*S)	7
A	B	: V=V/CABS(V)*RGI(J)*SQRT(VV)	7
A	B	: AR(1)=V	7
A	B	: AR(2)=-V	7
A	B	: AR(3)=-V	7
A	B	: AR(4)=V	7
A	B	: PH(1)=PI2*RT(J)	7
A	B	: PH(2)=PI2*(RT(J)+RDTS(J))	7
A	B	: PH(3)=PI2*(RT(J)+RDTR(J))	7
A	B	: PH(4)=PI2*(RT(J)+RDTR(J)+RDTS(J))	7
A	B	.....	7
A	B	I	7
A	B	I---[ COMPUTE BIG TRANSMISSION ]	7
A	B	I [COEFFICIENT ]	7
A	B	I	7
A	B	I	7
A	B	.....	7
A	B	: AR(5)=0	7
A	B	: AR(6)=0	7
A	B	: AR(7)=0	7
A	B	: AR(8)=C	7
A	B	.....	7
A	B	I	7
A	B	I	7
A	B	/.....\ TRUE	7
A	B	< IF(BTRF(J).EQ.0.)GO TO 205 >-----0	7
A	B	\...../ X	7
A	B	I FALSE X	7
A	B	I X	7
A	B	I X	7

```

A      /-----\ TRUE X Z
A      < IF(BT(J).LT.RT(J))GO TO 205 >-----V Z
A      \...../ X Z
A      I FALSE X Z
A      I X Z
A      I X Z
A      ..... X Z
A      : ALPH2=FPI2D*BSIN2(J)/2 : X Z
A      : C=COS(ALPH2) : X Z
A      : S=SIN(ALPH2) : X Z
A      : V=BTRF(J)/CMPLX((1+BV32(J)*BV21(J))*C,( : X Z
A      : BV32(J)*BV21(J)-1)*S)**2 : X Z
A      : V=V*BGI(J) : X Z
A      : AR(5)=V : X Z
A      : AR(6)=-V : X Z
A      : AR(7)=-V : X Z
A      : AR(8)=V : X Z
A      : V=CMPLX(BT(J),ALPH0*BLS(J)) : X Z
A      : PH(5)=PI2*V : X Z
A      : PH(6)=PI2*(V+BDTS(J)) : X Z
A      : PH(7)=PI2*(V+BDTR(J)) : X Z
A      : PH(8)=PI2*(V+BDTS(J)+BDTP(J)) : X Z
A      : ..... X Z
A      I X Z
A      O<-----0 7
A      [ 205] I 7
A      ..... 2
A      : CONTINUE : 7
A      : ..... 2
A      I 2
A      I---[ COMPUTE SMALL TRANSMISSION ] 2
A      I [COEFFICIENT ] 7
A      I 7
A      I 2
A      ..... 7
A      : ALPH2=FPI2D*SSIN2(J)/2 : 2
A      : C=COS(ALPH2) : 7
A      : S=SIN(ALPH2) : 2
A      : V=STRF(J)/CMPLX((1+SV32(J)*SV21(J))*C,( : 2
A      : SV32(J)*SV21(J)-1)*S)**2 : 2
A      : V=-V*SGI(J)*AIM : 2
A      : AR(9)=V : 2
A      : AR(10)=-V : 7
A      : AR(11)=-V : 7
A      : AR(12)=V : 7
A      : V=CMPLX(ST(J),ALPH0*SLS(J)) : 7
A      : PH(9)=PI2*V : 7
A      : PH(10)=PI2*(V+SDTS(J)) : 7
A      : PH(11)=PI2*(V+SDTR(J)) : 7
A      : PH(12)=PI2*(V+SDTS(J)+SDTR(J)) : 7
A      : ..... 7
A      I 7
A      I---[ COMPUTE BASEMENT RAY TRANSMISSION ] 7
A      I [N COEFFICIENT ] 7
A      I 7
A      I 7

```

A	:	ALPH2=FP12D*BSSIN2(J)/2	:	2
A	:	C=COS(ALPH2)	:	2
A	:	S=SIN(ALPH2)	:	2
A	:	V=BSTRF(J)/CMPLX((1+BSV32(J)*BSV21(J))*C,	:	2
A	:	(BSV32(J)*BSV21(J)-1)*S)**2	:	2
A	:	V=V*BSGI(J)*REF	:	2
A	:	AR(13)=V	:	2
A	:	AR(14)=-V	:	2
A	:	AR(15)=-V	:	2
A	:	AR(16)=V	:	2
A	:	V=CMPLX(BST(J),ALPH0*BSLS(J))	:	2
A	:	PH(13)=PI2*V	:	2
A	:	PH(14)=PI2*(V+BSDTS(J))	:	2
A	:	PH(15)=PI2*(V+BSDTR(J))	:	2
A	:	PH(16)=PI2*(V+BSDTS(J)+BSDTR(J))	:	2
A	:	V=0	:	2
A	:		:	2
A	:	I	:	2
A	:	I	:	2
A	:		:	2
A	B----->:	DO 210 K=1,15	:	2
A	B	:	:	2
A	B	I	:	2
A	B	I	:	2
A	B	:	:	2
A	B	NA=K+1	:	2
A	B	:	:	2
A	B	I	:	2
A	B	I	:	2
A	B	:	:	2
A	B	DO 210 L=NA,16	:	2
A	B	:	:	2
A	B	I	:	2
A	B	I	:	2
A	B	:	:	2
A	B	AUX99=AR(K)*CONJG(AR(L))	:	2
A	B	:	:	2
A	B	I	:	2
A	B	I	:	2
A	B	/	:	2
A	B	IF(CABS(AUX99).EQ.0.)GO TO 210	>-----0	2
A	B	/	X	2
A	B	I FALSE	X	2
A	B	I	X	2
A	B	I	X	2
A	B	:	X	2
A	B	AUX1=(PH(K)-CONJG(PH(L)))*AIM	X	2
A	B	:	X	2
A	B	I	X	2
A	B	I	X	2
A	B	/	:	2
A	B	IF(REAL(AUX1)*F2.LT.-40)GO TO 210	>-----V	2
A	B	/	X	2
A	B	I FALSE	X	2
A	B	I	X	2
A	B	I	X	2



A	B	C	.....	X	Z
A	B	C	: V=V+AUX99*(CEXP(F2*AUX1)-CEXP(F1*AUX1))/	X	Z
A	B	C	: AUX1	X	Z
A	B	C	.....	X	Z
A	B	C	I	X	Z
A	B	C	0<-----0		Z
A	B	C	[ 210] I		Z
A	B	C	.....		Z
A			CONTINUE		Z
A			.....		Z
A			I		Z
A			I		Z
A			.....		Z
A			: AUX=2*REAL(V)		Z
A			.....		Z
A			I		Z
A			I		Z
A			/.....\ TRUE		Z
A			< IF(CABS(AR(13)).EQ.0.)GO TO 209 >-----0		Z
A			\...../	X	Z
A			I FALSE	X	Z
A			I	X	Z
A			I	X	Z
A			.....	X	Z
A			: AUX2=-2*PI2*ALPHO*BSLS(J)	X	Z
A			.....	X	Z
A			I	X	Z
A			I	X	Z
A			/.....\ TRUE	X	Z
A			< IF(AUX2*F2.LT.-40)GO TO 209 >-----V		Z
A			\...../	X	Z
A			I FALSE	X	Z
A			I	X	Z
A			I	X	Z
A			.....	X	Z
A			: AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/	X	Z
A			: AUX2*CABS(AR(13))*2	X	Z
A			.....	X	Z
A			I	X	Z
A			0<-----0		Z
A			[ 200] I		Z
A			.....		Z
A			: AUX2=-2*PI2*ALPHO*BLS(J)		Z
A			: AUX2=-2*PI2*ALPHO*BLS(J)		Z
A			.....		Z
A			I		Z
A			I		Z
A			/.....\ TRUE		Z
A			< IF(AUX2*F2.LT.-40)GO TO 211 >-----0		Z
A			\...../	X	Z
A			I FALSE	X	Z
A			I	X	Z
A			I	X	Z
A			/.....\ TRUE	X	Z
A			< IF(CABS(AR(5)).EQ.0.)GO TO 211 >-----V		Z
A			\...../	X	Z
A			I FALSE	X	Z
A			I	X	Z
A			I	X	Z

A	.....		X	Z
A	: AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/	:	X	Z
A	: AUX2*CABS(AR(5))*2	:	X	Z
A	.....		X	Z
A	I		X	Z
A	0<-----	0		Z
A	[ 211]	I		Z
A	.....			Z
A	: AUX2=-2*PI2*ALPH0*SLS(J)	:		Z
A	.....			Z
A	I			Z
A	I			Z
A	/.....\ TRUE			Z
A	< IF(AUX2*F2.LT.-40)GO TO 212 >-----	0		Z
A	/.....\		X	Z
A	I FALSE		X	Z
A	I		X	Z
A	I		X	Z
A	/.....\ TRUE		X	Z
A	< IF(CABS(AR(9)).EQ.0.)GO TO 212 >-----	V		Z
A	/.....\		X	Z
A	I FALSE		X	Z
A	I		X	Z
A	I		X	Z
A	.....		X	Z
A	: AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/	:	X	Z
A	: AUX2*CABS(AR(9))*2	:	X	Z
A	.....		X	Z
A	I		X	Z
A	0<-----	0		Z
A	[ 212]	I		Z
A	.....			Z
A	: AUX=AUX/F1+4*CABS(AR(1))*2	:		Z
A	.....			Z
A	I			Z
A	I			Z
A	/.....\ TRUE			Z
A	< IF(AUX.GT.0.)GO TO 213 >-----	0		Z
A	/.....\		X	Z
A	I FALSE		X	Z
A	I		X	Z
A	I		X	Z
A	.....		X	Z
A	: ALOSS(JJ,J)=25.	:	X	Z
A	.....		X	Z
A	I		X	Z
A	I		X	Z
A	/.....\		X	Z
A	: GO TO 200 :-----	0	X	Z
A	/.....\		U	X
A			U	X
A			U	Y
A	0<-----	0		Z
A	[ 213]	I	U	Z

A	.....	U	7
A	: ALOSS(JJ,J)=-10.*ALOG10(AUX/(2.*RGI(J))**	U	7
A	: 2)	U	7
A	.....	U	7
A	I	U	7
A	0<-----0		7
A	[ 200]		7
A	.....		7
A	CONTINUE		7
A	.....		7
A	I		7
A	[ 700]		7
A	.....		7
A	N=J-1		7
A	NA=J		7
A	.....		7
A	I		7
A	I		7
A	.....		7
A	DO 701 I=1,N		7
A	.....		7
A	I		7
A	I		7
A	.....		7
A	J=NA-I		7
A	.....		7
A	I		7
A	I		7
A	.....		7
A	IF(J.LT.NSAP)GO TO 999	TRUE	7
A	.....	0	7
A	I FALSE	X	7
A	I	X	7
A	I	X	7
A	.....	X	7
A	DR=PI2*RDTR(J)	X	7
A	DS=PI2*RDTS(J)	X	7
A	AUX=DR+DS	X	7
A	DT=SIN(F2*AUX)-SIN(F1*AUX)	X	7
A	DT=DT/AUX	X	7
A	AUX=DS-DR	X	7
A	DT=DT+SIN(F2*AUX)/AUX-SIN(F1*AUX)/AUX	X	7
A	DT=DT-2*(SIN(F2*DS)-SIN(F1*DS))/DS	X	7
A	DT=DT-2*(SIN(F2*DR)-SIN(F1*DR))/DR	X	7
A	DT=DT/2/F1+1	X	7
A	ALOSS(JJ,J)=-10.*ALOG10(DT)	X	7
A	.....	X	7
A	I	X	7
A	[ 701]	X	7
A	.....	X	7
A	CONTINUE	X	7
A	.....	X	7
A	I	X	7
A	I	X	7
A	.....	X	7
A	GO TO 999	V	7
A	.....	X	7

				X	7
				X	7
		0<-----			0
	[ 800]	I		X	
	.....			X	
	:	N=J-1	:	X	
	:	NA=J	:	X	
	.....			X	
		I		X	
		I		X	
	.....			X	
A-->	:	DO 801 I=1,N	:	X	
A	.....			X	
A		I		X	
A		I		X	
A	.....			X	
A	:	J=NA-I	:	X	
A	.....			X	
A		I		X	
A		I		X	
A	/.....\			X	
A	<	IF(J.LT.NTIR)GO TO 999	>-----	V	
A	/.....\			X	
A		I FALSE		X	
A		I		X	
A		I---[ COMPUTE BIG TRANSMISSION ]		X	
A		I [COEFFICIENT ]		X	
A		I		X	
A		I		X	
A	.....			X	
A	:	ALOSS(JJ,J)=25.	:	X	
A	:	ALPH2=FPI2D*BSIN2(J)	:	X	
A	:	C=COS(ALPH2)	:	X	
A	:	S=SIN(ALPH2)	:	X	
A	:	V=BTRF(J)/CMPLX((1+BV32(J)*BV21(J))*C,(	:	X	
A	:	BV32(J)*BV21(J)-1)*S)**2	:	X	
A	:	V=V*BGI(J)	:	X	
A	:	AUX3=CABS(V)**2	:	X	
A	.....			X	
A		I		X	
A		I		X	
A	/.....\			X	
A	<	IF(AUX3.EQ.0)GO TO 801	>-----	0	
A	/.....\			X	7
A		I FALSE		X	7
A		I		X	7
A		I		X	7
A	.....			X	7
A	:	DR=PI2*BDTR(J)	:	X	7
A	:	DS=PI2*BDTS(J)	:	X	7
A	:	AUX=DR+DS	:	X	7
A	:	DT=SIN(F2*AUX)-SIN(F1*AUX)	:	X	7
A	:	DT=DT/AUX	:	X	7
A	:	AUX=DS-DR	:	X	7
A	:	DT=DT+SIN(F2*AUX)/AUX-SIN(F1*AUX)/AUX	:	X	7
A	:	DT=DT-2*(SIN(F2*DS)-SIN(F1*DS))/DS	:	X	7
A	:	DT=DT-2*(SIN(F2*DR)-SIN(F1*DR))/DR	:	X	7
A	:	DT=DT/2/F1+1	:	X	7
A	:	AUX2=-2*PI2*ALPHJ*BLS(J)*EX	:	X	7
A	.....			X	7

A		I		X	2
A		I		X	2
A	/			X	2
A	<	IF(AUX2*F2.LT.-40.)GO TO 801	>		V
A	\	...../		X	7
A		I FALSE		X	2
A		I		X	2
A		I		X	7
A	.....			X	2
A	:	ALOSS(JJ,J)=-10*(AUX2+ALOG10(AUX3*DT/RGI(	:	X	2
A	:	J)**2))	:	X	2
A	:	.....	:	X	2
A		I		X	7
A		I		X	2
A	/			X	2
A	<	IF(ALOSS(JJ,J).GT.25.)	>		I
A	\	...../		I	X
A		I TRUE		I	X
A		I		I	X
A	.....			I	X
A	:	ALOSS(JJ,J)=25	:	I	X
A	:	.....	:	I	X
A		I		I	X
A		0<			0
A	[ 801]	I		X	
A	.....			X	
A	:	CONTINUE	:	X	
A	:	.....	:	X	
A		I		X	
A		0<			0
A	[ 999]	I			
A	:	RETURN	:		
A	:	.....	:		



```

.....
\ SUBROUTINE GCOMP /
\ .....
I
I---[ THIS SUBROUTINE COMPUTES THE ]
I [ GRADIENT (G) ]
I [ AND ITERATES TO FIND THE ACTUAL ]
I [ CRITICAL ]
I [ ANGLE (THC). BOTH ARE THEN ]
I [ RETURNED TO THE ]
I [ MAIN PROGRAM. ]
I
I
.....
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
: ALPHD,CS,BZ,REF :
: COMMON /DATA/LZERO,FZERO,L70,F70,TH70, :
: L71,F71,DBLOSS,FREQ,THETA, ALOSS0,ALOSSM, :
: FM,TIP,THC,THRC,TH1B,BETA :
: :
: REAL LZERO,L70,L71 :
: :
: PI=3.14159265 :
: :
: THRC=30. :
: :
: THCD=THC :
: :
: B=BETA :
: :
: THRC=THRC*(PI/180.) :
: :
: THINC=1. :
: :
: D1=2*ZR-ZR-ZS :
: :
: TH3=ACOS((C3/C1)*COS(THRC)) :
: :
: FACT1=(2.*C3*B)/(1.+B) :
: :
: SIN3=SIN(TH3) :
: :
: COS3=COS(TH3) :
: :
: SIN3SQ=SIN3*SIN3 :
: :
: COS3SQ=COS3*COS3 :
: :
: FACT2=1.+(1./(2.*B))*(1.+(TH3/(SIN3*COS3) :
: )) :
: :
: GZERO=(FACT1*(1./COS3SQ)*FACT2+(C3/(1.+B) :
: )*(1./COS3SQ)*(1.-((TH3*(COS3SQ-SIN3SQ) :
: /(SIN3*COS3))))*(C3/C1)*(SIN(THRC)/ :
: SIN3))/(D1/SIN(THRC))*2) :
: :
: R=(D1/TAN(THRC))+(FACT1*TAN(TH3)/GZERO)* :
: FACT2 :
: :
: :
: THC1=ATAN(D1/R) :
: :
: THC1=THC1*(180./PI) :
: :
: MAXIT=100 :
: :
.....
I
I
[ 100] I
.....
: DO 600 IT=1,MAXIT :
: .....
I
I

```

```

A .....
A :          THRC=THRC*(180./PI)          :
A :          THRC=THRC+THINC              :
A :          THRC=THRC*(PI/180.)          :
A :          TH3=ACOS((C3/C1)*COS(THRC))  :
A :          FACT1=(2.*(C3*B)/(1.+B))     :
A :          SIN3=SIN(TH3)                :
A :          COS3=COS(TH3)                :
A :          SIN3SQ=SIN3*SIN3             :
A :          COS3SQ=COS3*COS3             :
A :          FACT2=1.+(1./(2.*B))*(1.+(TH3/(SIN3*COS3) :
A :          ))                           :
A :          GZERO=(FACT1*(1./COS3SQ)*FACT2+(C3/(1.+B) :
A :          )*(1./COS3SQ)*(1.-((TH3*(COS3SQ-SIN3SQ)) :
A :          /(SIN3*COS3))))*((C3/C1)*(SIN(THRC)/ :
A :          SIN3))/(D1/SIN(THRC)**2)     :
A :          R=(D1/TAN(THRC))+(FACT1*TAN(TH3)/GZERO)* :
A :          FACT2                         :
A :          THC2=ATAN(D1/R)               :
A :          THC2=THC2*(180./PI)          :
A .....
A :          I                             :
A :          I                             :
A :          /.....\ TRUE
A < IF(ABS(THC0-THC1).LE. 1.E-4) GO TO 700 >-----0
A \...../
A :          I FALSE
A :          I
A :          I
A :          /.....\ TRUE
A < IF(((THC0-THC1)*(THC0-THC2)) .GE. 0.) GO >-----0
A < TO 500 >
A \...../
A :          I FALSE
A :          I
A :          I
A :          .....
A :          THINC= -THINC/2.
A :          .....
A :          I
A :          0<-----0
A [ 500] I
A :          .....
A :          THC1=THC2
A :          .....
A :          I
A [ 600] I
A :          .....
A :          CONTINUE
A :          .....
A :          I
A :          I
A :          /...../
A :          WRITE(1,650) MAXIT,THC0,THC2
A :          /...../

```

	I		Z
	I---	[ 650 FORMAT(1X,15,2X,ITERATIONS)	Z
	I	[AND STILL NO SOLUTION,/, 1 1X,]	Z
	I	[THC0=,F10.6,5X,THC2=,F10.6) ]	Z
	I		Z
	I		Z
	:	/.....\	Z
	:	GO TO 800	Z
	:	.....	X
			X
			X
			0
		0<-----	0
[ 700]	I		X
:	:	.....	X
:	:	THC=THC2	X
:	:	G=GZERO	X
:	:	.....	X
	I		X
		0<-----	0
[ 800]	I		
:	:	/.....\	
:	:	RETURN	
:	:	.....	

```

      /-----\
      : BEGIN :
      \...../

      I
      I

.....:
:      BLOCK DATA NULL :
: COMMON /DATA/ALZERO,FZERO,AL70,F70,TH70, :
: AL71,F71,DBLOSS,FREQ, THETA,ALOSS0, :
: ALOSSM,FM,TIR,TMC,THRC,TH1B,BETA :
:      COMMON /ALPH/GAM :
:      COMMON /T/T :
: COMMON /R/NSAP,RV21(90),RV32(90),RSIN2( :
: 90),RDTS(90),RDTR(90), RT(90),RGI(90) :
: COMMON /B/BV21(90),RV32(90),BSIN2(90), :
: BTRF(90),RGI(90),BLS(90), BT(90),BDTS(90) :
: ,BDTR(90) :
: COMMON /S/SV21(90),SV32(90),SSIN2(90), :
: STRF(90),SGI(90),SLS(90), ST(90),SDTS(90) :
: ,SDTR(90) :
: COMMON /BS/BSV21(90),BSV32(90),BSSIN2(90) :
: ,BSTRF(90),BSGI(90), BSLS(90),BST(90), :
: BSDTS(90),BSDTR(90) :
:      COMMON/AL/F(6),ALOSS(6,90) :
: DATA F/50.,100.,200.,400.,800.,1600./ :
.....:

      I
      I

      /-----\
      : END :
      \...../

```

## APPENDIX C

### RUN STREAM

An example of the computer input run stream for each of the two input options follows.

:RUN,BTLS9

INPUT OPTIONS ARE: 0 = INPUT GEO-PARAMETERS

1 = INPUT BOTTOM LOSS

2 = END PROGRAM

ENTER STATION NUMBER AND INPUT OPTION:

8 0

ENTER THE TWO-WAY TRAVEL TIME THICKNESS IN 10THS OF SECONDS:

4.58

ENTER THE WATER DEPTH:

1800.0

ENTER SOURCE DEPTH AND RECEIVER DEPTH:

244.0 305.0

ENTER SOUND SPEED AT SOURCE OR RECEIVER - WHICHEVER IS SHALLOWER:

1511.72

ENTER SOUND SPEED AT THE BOTTOM OF THE WATER:

1535.11

ENTER RATIO OF SPEED IN SEDIMENT TO SPEED AT BOTTOM OF WATER:

.996

ENTER GRADIENT AT TOP OF SEDIMENT AND CANONICAL CURVE TYPE:

1.7 .86

ENTER THIN LAYER DENSITY, SEDIMENT DENSITY AND THIN LAYER THICKNESS IN METERS:

2.33 2.33 .04



ENTER SURFACE ATTENUATION IN DB/M/KHZ:

.021

ENTER ATTENUATION PROFILE GRADIENT AND BASEMENT REFLECTION COEFFICIENT IN  
PRESSURE:

.00015 .708

RUN,BTLS9

INPUT OPTIONS ARE: 0 = INPUT GEO-PARAMETERS

1 = INPUT BOTTOM LOSS

2 = END PROGRAM

ENTER STATION NUMBER AND INPUT OPTION:

8 1

ENTER THE TWO-WAY TRAVEL TIME THICKNESS IN 10THS OF SECONDS:

4.58

ENTER THE WATER DEPTH:

1800.0

ENTER SOURCE DEPTH AND RECEIVER DEPTH:

244.0 305.0

ENTER SOUND SPEED AT SOURCE OR RECEIVER - WHICHEVER IS SHALLOWER:

1511.72

ENTER SOUND SPEED AT THE BOTTOM OF THE WATER:

1535.11

#### ATTENUATION CALCULATION

FOR A POINT BELOW THE CAUSTIC WHERE BL CURVE IS NEARLY LINEAR,

ENTER A LOSS, FREQUENCY AND ANGLE: (ANG=APPROX 20, FREQ = APPROX 200)

5 20 200

ENTER LOW FREQ LOSS LEVEL AT HIGH ANGLES,

THE MINIMUM LOSS LEVEL AT HIGH ANGLES

AND THE FREQUENCY OF THE MINIMUM LOSS:

10 6 80

ENTER ANGLE OF TOTAL INTERNAL REFLECTION,

ANGLE OF CAUSTIC,

RATIO OF SPEED IN SEDIMENT TO SPEED AT BOTTOM OF WATER:

55 34 .996

ENTER CANONICAL CURVE TYPE AND ATTENUATION PROFILE GRADIENT:

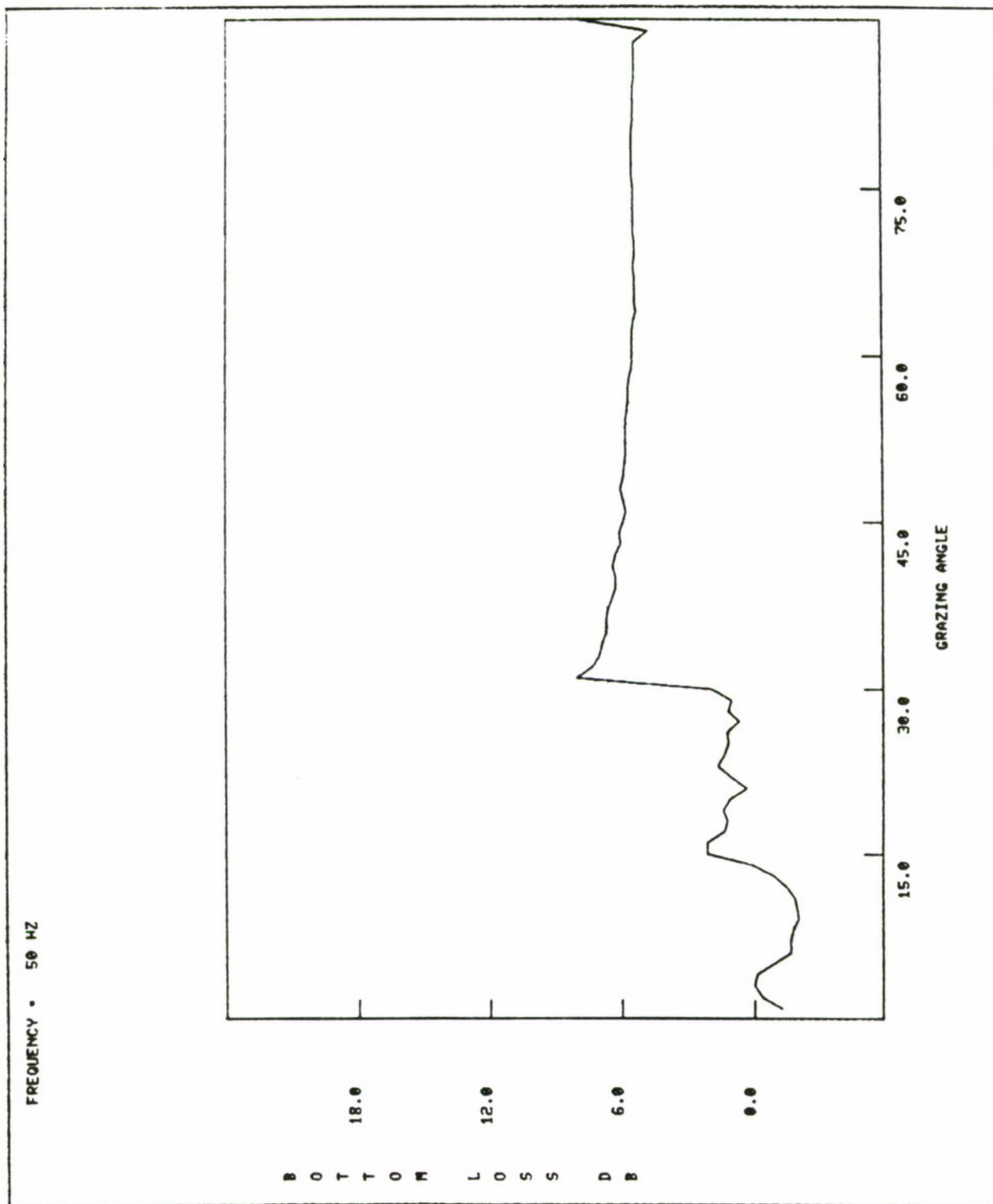
.86 1.7

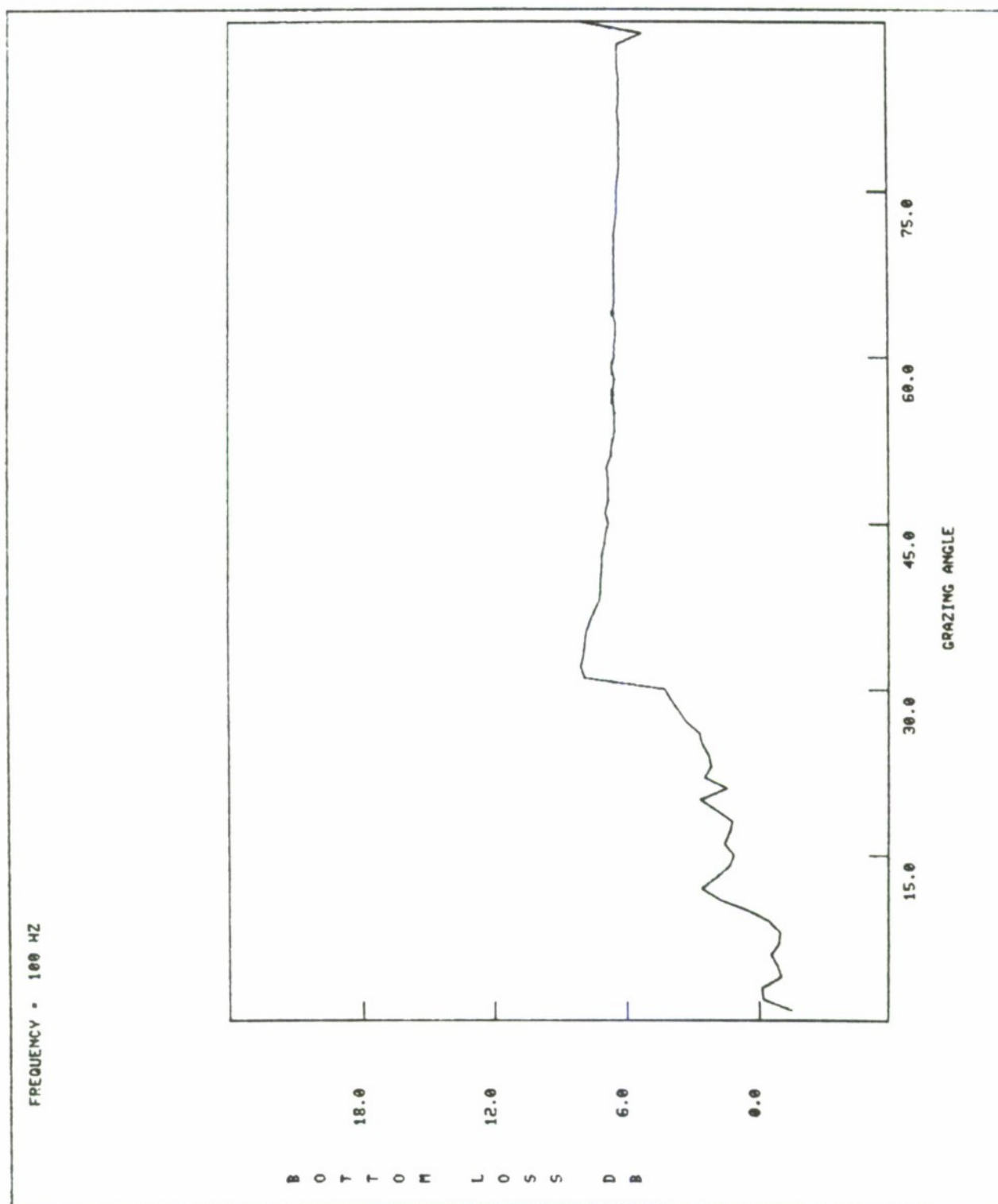
ENTER BASEMENT REFLECTION COEFFICIENT IN PRESSURE UNITS:

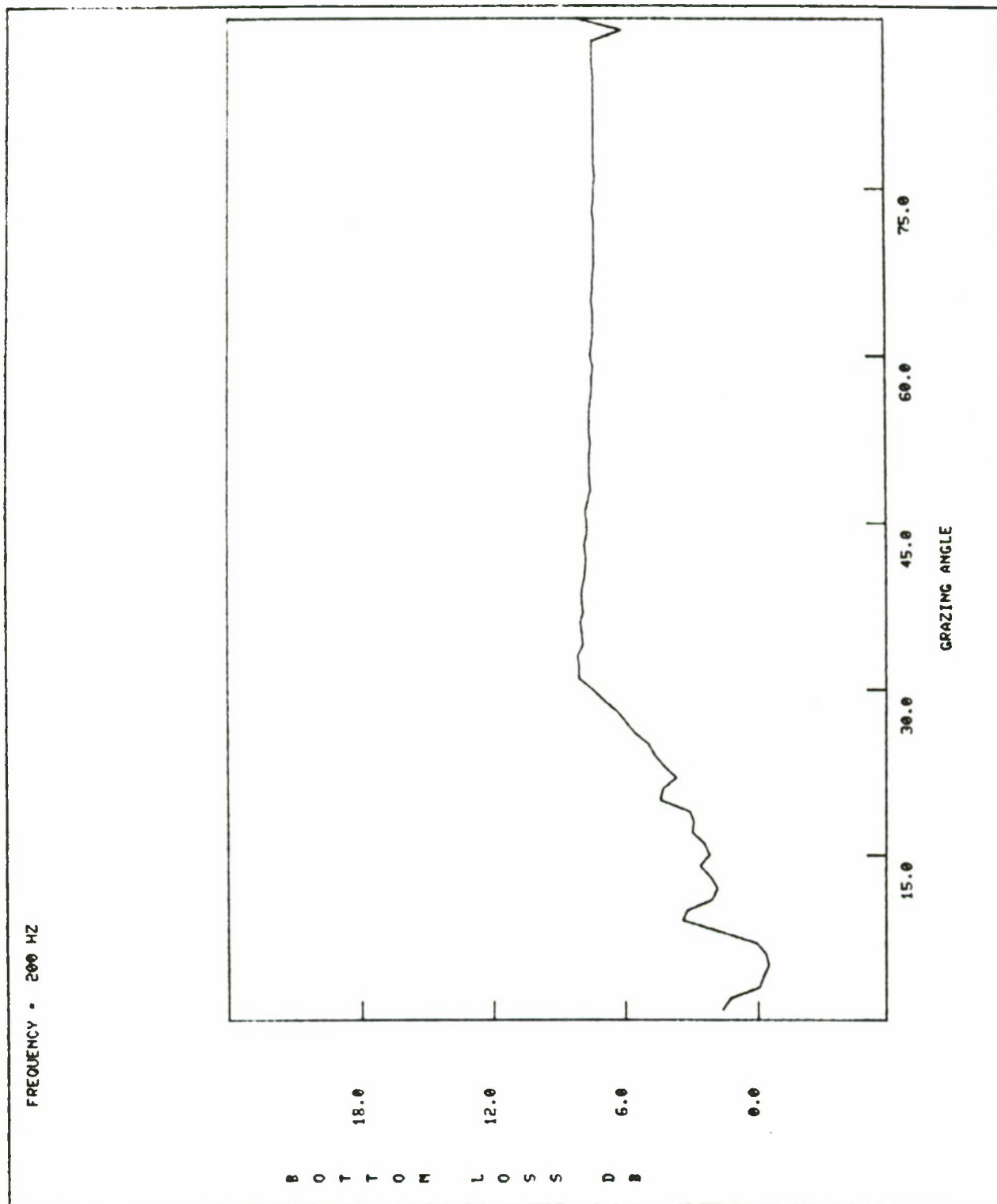
.708

/BTL14 \*RUNTIME ERROR\* 22UN @ 40126

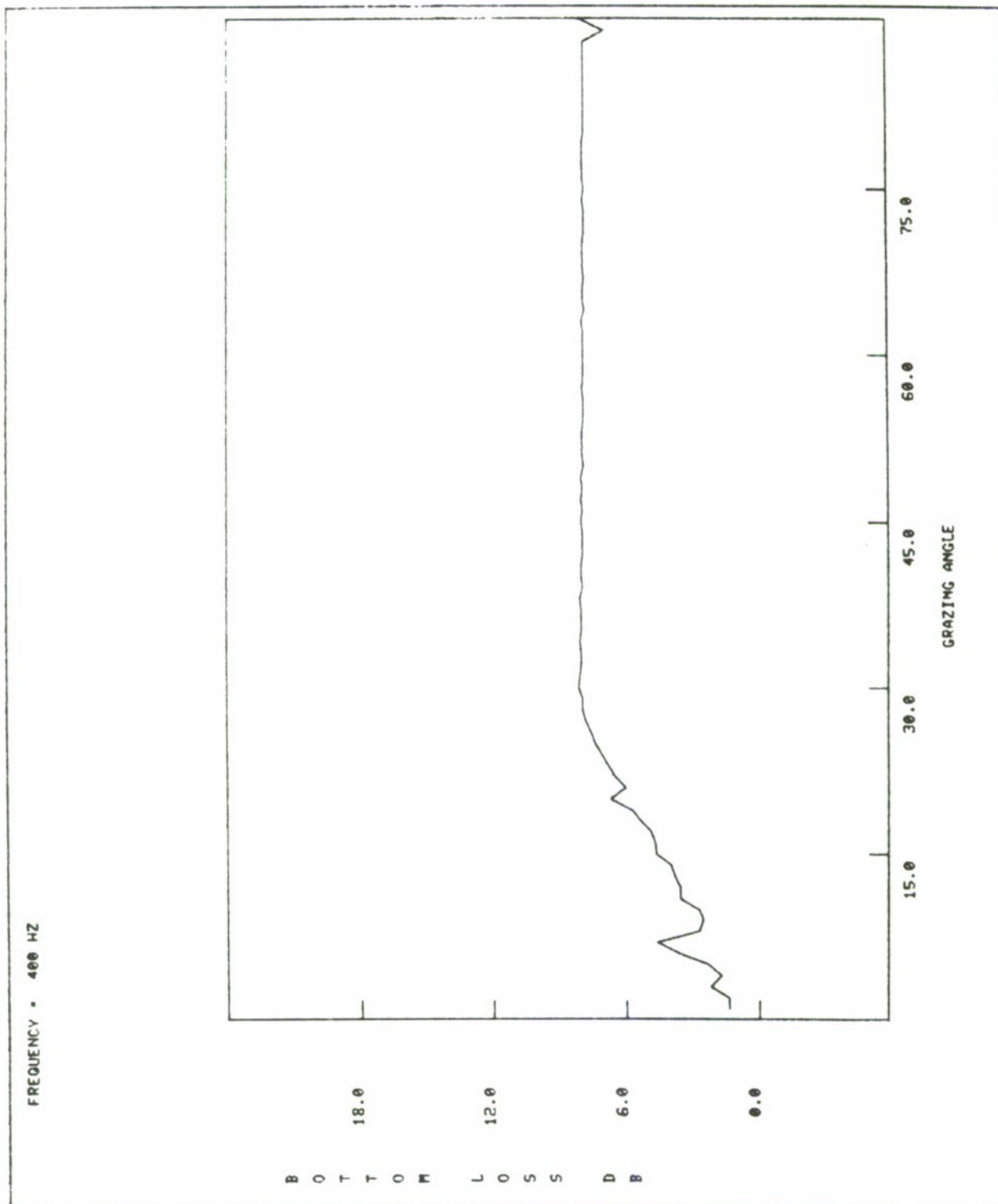
/BTL14 \*RUNTIME ERROR\* 22UN @ 4022

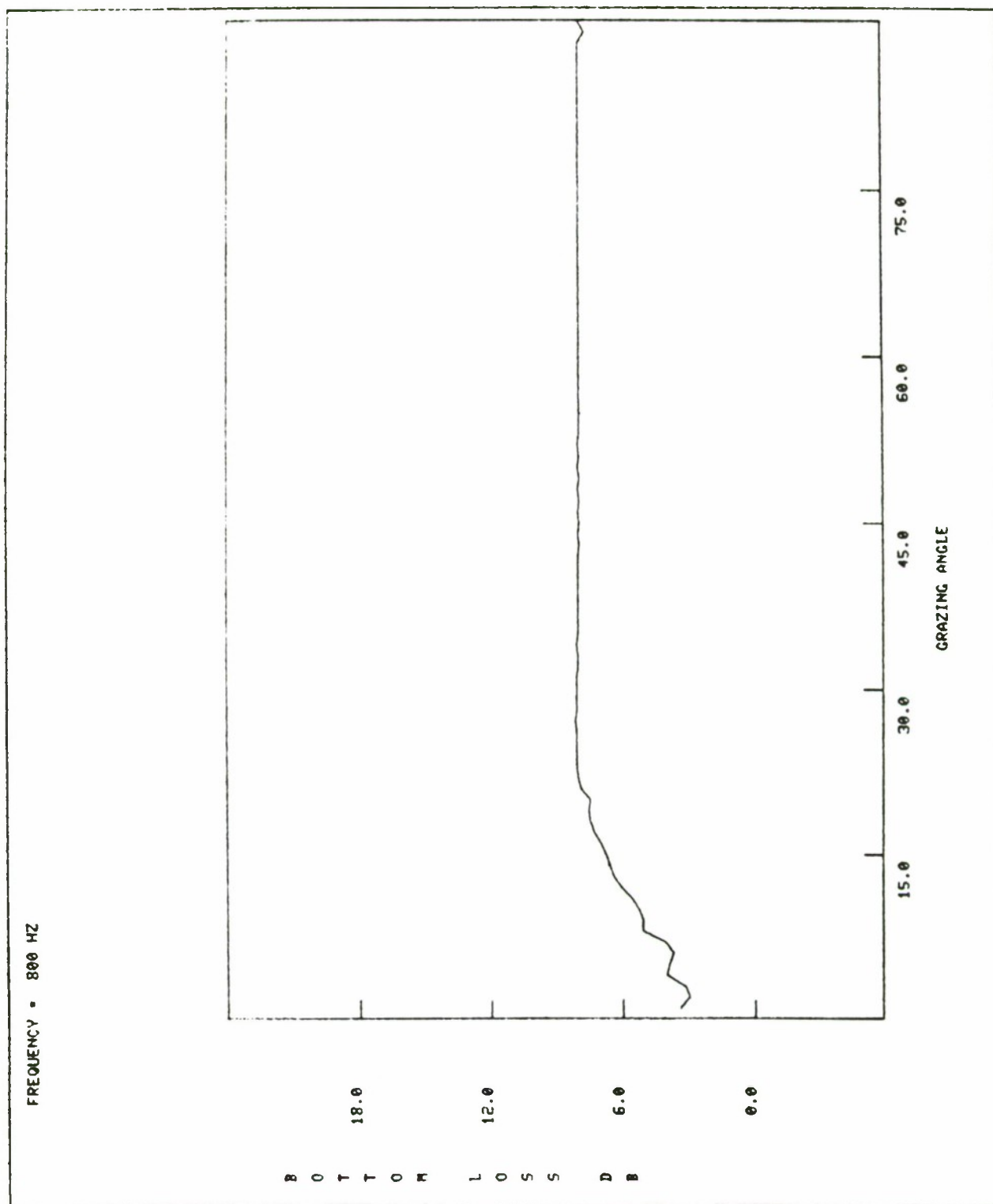


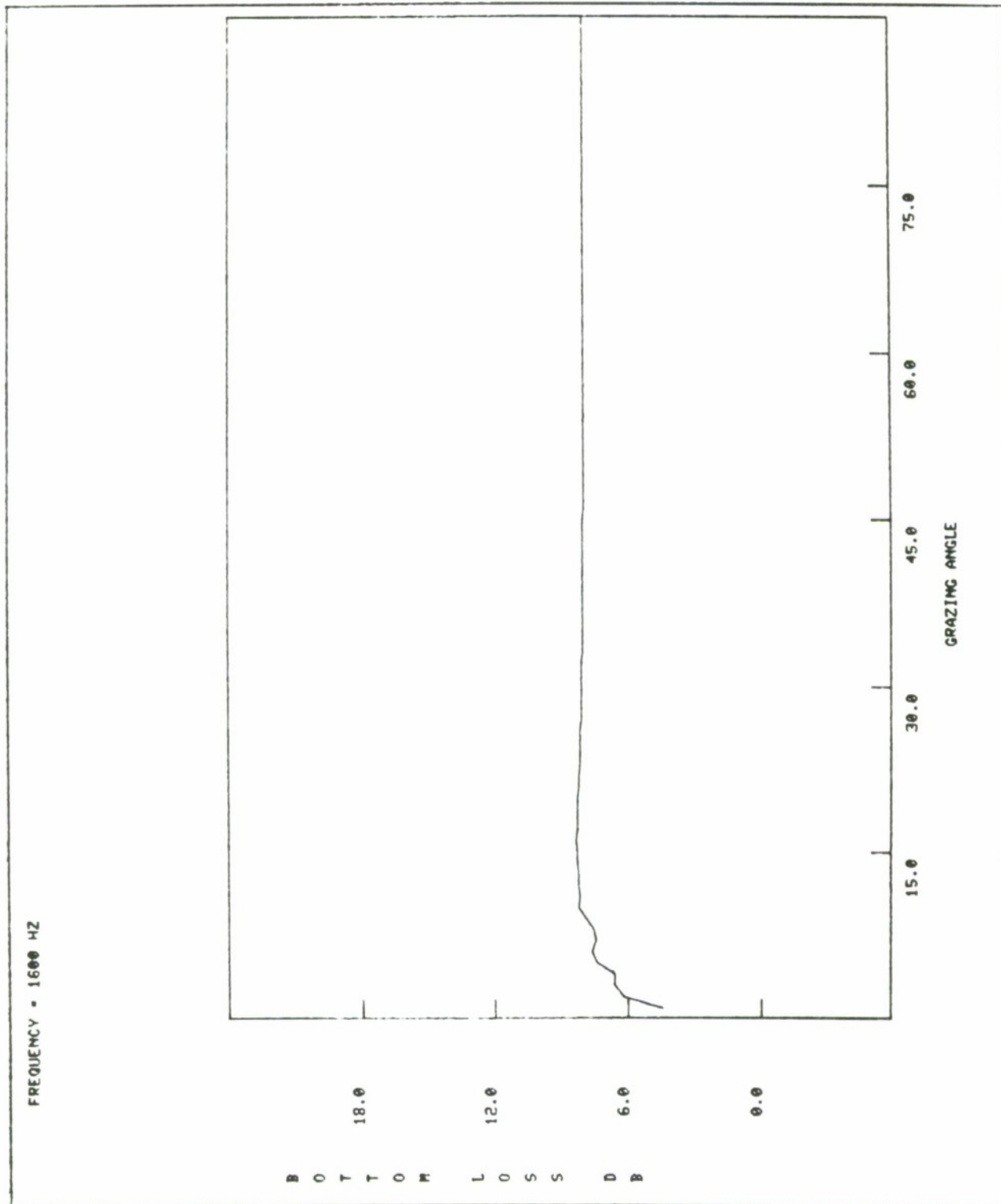












KT110

INPLT OPTIONS ARE: 0 • INPUT GEO-PARAMETERS  
1 • INPUT BOTTOM LOSS  
2 • END PROGRAM

ENTER STATION NUMBER AND INPLT OPTION:

3 0

ENTER THE TWO-WAY TRAVEL TIME THICKNESS IN 10THS OF SECONDS:

4.52

ENTER THE WATER DEPTH:

1300

ENTER SOURCE DEPTH AND RECEIVER DEPTH:

244 305

ENTER SOUND SPEED AT SOURCE OR RECEIVER - WHICHEVER IS SHALLOWER:

1511.7

ENTER SOUND SPEED AT THE BOTTOM OF THE WATER:

1535.1

ENTER RATIO OF SPEED IN SEDIMENT TO SPEED AT BOTTOM OF WATER:

.996

ENTER GRADIENT AT TOP OF SEDIMENT AND CANONICAL CURVE TYPE:

1.7 .86

ENTER THIN LAYER DENSITY, SEDIMENT DENSITY AND THIN LAYER THICKNESS IN METERS:

2.33 2.33 .04

ENTER SURFACE ATTENUATION IN DB/M/KHZ:

.021

ENTER ATTENUATION PROFILE GRADIENT AND BASEMENT REFLECTION COEFFICIENT IN PRESSURE:

.00015 .708

# OUTPUT OF COMPUTER RUN

## CRITICAL ANGLES

TIR = 0.00 RAT = .9960 THC = 30.74 THRC = 46.97  
 THB = 30.67 THRB = 45.07  
 TWTT = .46 BZ = 422.13 CRD = 477.57  
 G500 = 1.34 C500 = 2279.83 A500 = .096 GAM = .00015

## GEO-PARAMETERS

RAT = .9960  
 RH2 = 2.33 RH3 = 2.33  
 D = .04  
 G = 1.70 BET = .86  
 AL0 = .021 GAM = .00015  
 BZ = 422.13 REF = .71

-1.25	-.32	.05	-.11	-.88	-1.65	-1.68	-1.79
-2.02	-1.97	-1.81	-1.45	-.86	.15	2.22	2.21
1.42	1.29	1.47	1.19	.37	1.09	1.71	1.42
1.24	1.30	.77	1.20	1.11	2.03	8.07	7.35
7.07	6.95	6.75	6.74	6.67	6.54	6.35	6.31
6.47	6.33	6.10	6.12	5.99	5.82	5.97	6.09
5.98	5.89	5.82	5.82	5.83	5.86	5.79	5.76
5.75	5.69	5.55	5.53	5.56	5.57	5.48	5.39
5.40	5.43	5.45	5.47	5.45	5.46	5.49	5.50
5.50	5.51	5.52	5.52	5.52	5.52	5.52	5.52
5.51	5.49	5.48	5.46	5.45	5.45	5.45	5.45
4.78	7.87						
-1.47	-.14	-.10	-.97	-.83	-.51	-.85	-.91
-.39	.54	1.81	2.65	2.00	1.41	1.25	1.66
1.41	1.30	1.96	2.71	1.52	2.57	2.26	2.36
2.68	2.80	3.39	3.68	4.07	4.35	7.93	8.13
7.99	7.94	7.89	7.69	7.55	7.27	7.24	7.23
7.16	7.16	7.06	7.00	6.85	6.97	6.89	6.87
6.85	6.91	6.75	6.72	6.57	6.57	6.58	6.62
6.62	6.58	6.70	6.58	6.58	6.50	6.53	6.62
6.57	6.57	6.55	6.56	6.56	6.56	6.58	6.53
6.43	6.42	6.43	6.41	6.35	6.32	6.33	6.34
6.36	6.36	6.35	6.35	6.35	6.37	6.37	6.38
5.28	7.95						
1.64	1.27	-.05	-.20	-.46	-.32	.07	1.74
3.44	3.30	2.16	1.88	2.20	2.69	2.23	2.48
3.00	2.99	3.13	4.45	4.38	3.74	4.26	4.71
5.01	5.58	6.02	6.41	7.02	7.55	8.11	8.14
8.17	7.95	8.00	8.06	7.95	7.98	7.99	7.90
7.81	7.82	7.91	7.76	7.80	7.82	7.74	7.62
7.65	7.62	7.65	7.56	7.62	7.65	7.66	7.58
7.51	7.52	7.50	7.57	7.50	7.49	7.50	7.50
7.51	7.45	7.45	7.39	7.39	7.41	7.41	7.40
7.48	7.42	7.41	7.36	7.42	7.42	7.41	7.41
7.42	7.43	7.44	7.43	7.43	7.44	7.44	7.45
6.08	8.08						
1.43	1.39	2.27	1.75	2.38	3.67	4.64	2.78
2.64	2.79	3.62	3.66	3.88	4.06	4.73	4.79
4.94	5.45	5.76	6.77	6.06	6.60	6.84	7.18
7.46	7.64	7.88	8.03	8.03	8.17	8.13	8.07
8.08	8.10	8.08	8.06	8.04	8.12	8.03	8.05



8.07	8.02	8.02	8.02	8.07	7.99	8.05	8.03
8.05	7.97	8.03	8.02	8.03	7.95	7.96	7.96
7.99	7.96	7.94	7.95	7.94	7.96	7.99	7.91
7.93	7.97	7.91	7.95	7.96	7.93	7.90	7.92
7.91	7.92	7.89	7.93	7.93	7.94	7.95	7.91
7.90	7.88	7.89	7.90	7.90	7.90	7.90	7.90
6.93	8.00						
3.44	3.01	3.18	4.06	3.94	3.73	4.08	5.13
5.11	5.33	5.60	6.07	6.44	6.64	6.83	7.07
7.37	7.55	7.60	7.52	7.92	8.04	8.11	8.16
8.11	8.16	8.16	8.12	8.13	8.10	8.11	8.10
8.08	8.11	8.08	8.05	8.08	8.06	8.09	8.06
8.05	8.05	8.03	8.05	8.04	8.05	8.03	8.05
8.02	8.05	8.03	8.04	8.02	8.03	8.01	8.02
8.03	8.03	8.03	8.01	8.02	8.02	8.01	8.02
8.02	8.01	8.02	8.03	8.01	8.01	8.02	8.01
8.00	8.02	8.02	8.02	8.01	8.00	8.00	8.01
8.00	8.01	8.02	8.02	8.00	8.00	7.99	7.99
7.72	8.00						
4.49	6.21	6.63	6.65	7.42	7.63	7.45	7.59
7.94	8.25	8.18	8.27	8.25	8.31	8.31	8.34
8.31	8.32	8.32	8.28	8.28	8.23	8.20	8.19
8.18	8.16	8.15	8.13	8.14	8.11	8.11	8.11
8.09	8.08	8.08	8.08	8.09	8.06	8.06	8.07
8.05	8.06	8.06	8.05	8.05	8.03	8.03	8.03
8.03	8.03	8.03	8.02	8.03	8.03	8.03	8.03
8.02	8.02	8.02	8.02	8.02	8.02	8.01	8.02
8.02	8.01	8.02	8.01	8.02	8.01	8.01	8.01
8.02	8.01	8.01	8.00	8.01	8.02	8.00	8.01
8.01	8.01	8.00	8.01	8.01	8.00	8.01	8.01
7.99	8.01						

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